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AN OLD DUTCH WINDMILL AND A MODERN FRENCH AEROPLANE

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PRACTICAL AERONAUTICS

AN UNDERSTANDABLE PRESENTATION OF INTERESTING AND ESSENTIAL FACTS IN AERONAUTICAL SCIENCE

By

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WITH INTRODUCTION BY
ORVILLE WRIGHT

ILLUSTRATED

CHICAGO
AMERICAN SCHOOL OF CORRESPONDENCE
1912

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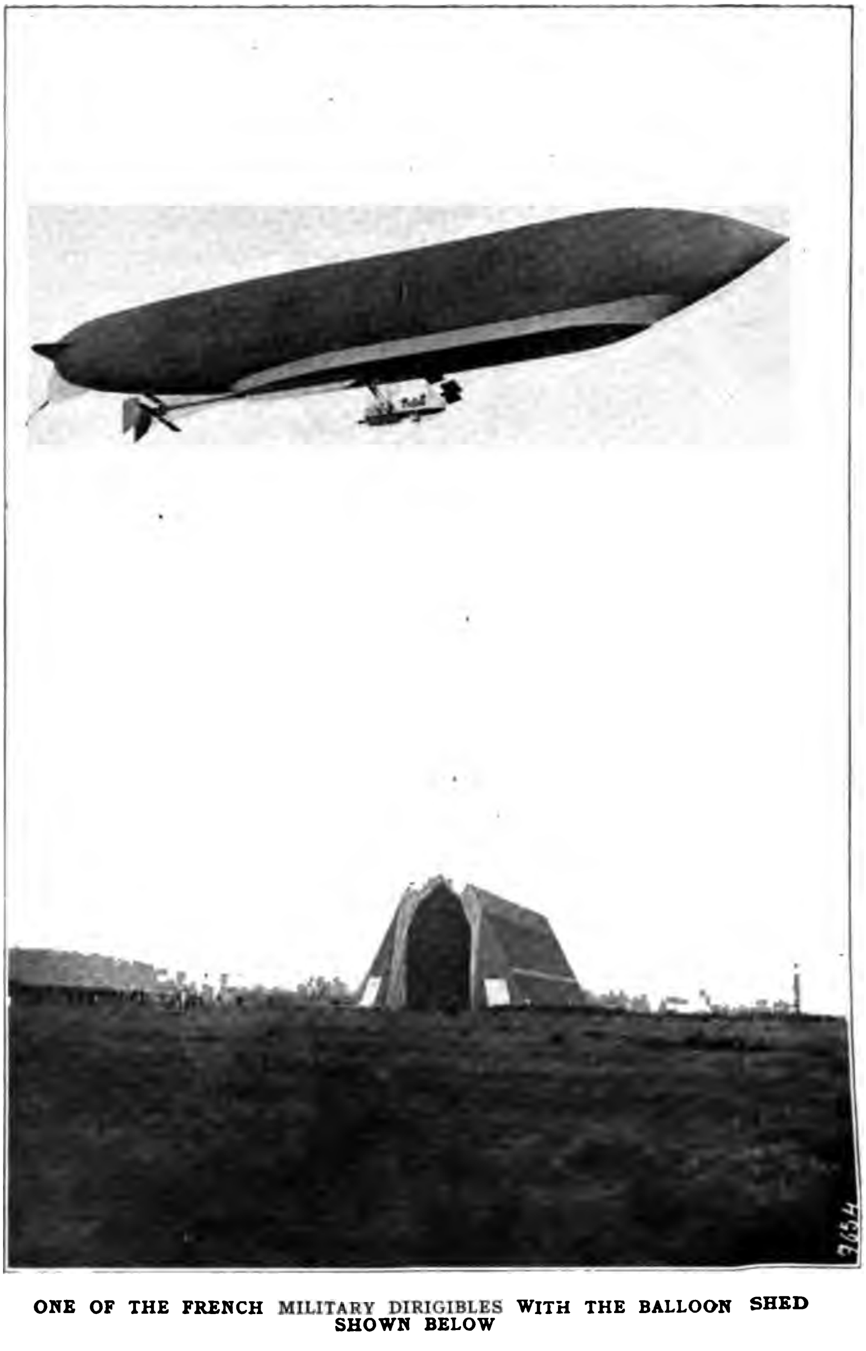
INTRODUCTION

THE achievement of flight by man after ages of disappointment has so aroused the imagination and the interest of the public that a great demand has been created for works treating on this subject. A number of authors have attempted to supply this demand. Some, having no real historical or scientific knowledge of the subject, have been compelled to draw their materials from the imaginative stories of newspaper writers. Others, with some knowledge of engineering and physics but with no practical experience in aeronautics, have fallen into serious errors in their attempts to explain the principles of flight. This has resulted in the publication of a great many works that might better have been left unprinted.

At the request of the author I have looked over some of the proofs of the present work. On account of lack of time I have not been able to read all the chapters as I should like, but those I have examined, such as the chapters treating of the work of the early experimenters and the present status of the patent litigation, are remarkably free from the errors usually found in aeronautical works of this character. The story of the early work of my brother and myself is also correct, and is taken almost verbatim from an article written by us several years ago for the *Century Magazine*. The chapter on the patent litigation is the best and clearest presentation of the legal aspect of the subject that has come to my notice. If the portions of the book which I have not examined have been prepared with the same care and accuracy as those I have read, I am sure the work will be a valuable addition to the literature of Aeronautics.

Orville Wright



ONE OF THE FRENCH MILITARY DIRIGIBLES WITH THE BALLOON SHED SHOWN BELOW

DIRIGIBLE BALLOONS

INTRODUCTION

Of the first attempts of men to emulate the flight of birds, we have no knowledge, but one of the earliest, perhaps, is embodied in the myth of Icarus and Daedalus. Xerxes, it is said, possessed a throne which was drawn through the air by eagles. The Chinese have sometimes been given credit for the invention of the balloon, as they have for many other scientific discoveries. It is related that a balloon was sent up at Pekin in celebration of the ascension of the throne by an emperor in the beginning of the fourteenth century.

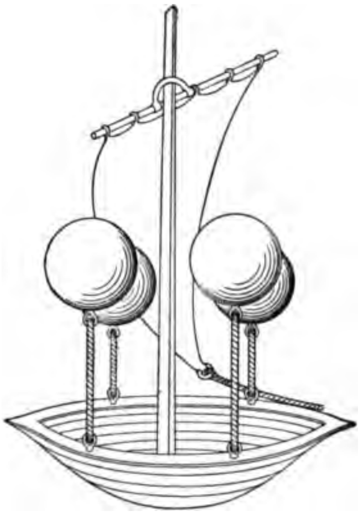


Fig. 1. De Lana Airboat

Early Attempts. Leonardo da Vinci devoted some time to the problem of artificial flight. His sketches show the details of bat-like wings which were to spread out on the downward stroke and fold up with the upward stroke. Francisco de Lana planned to make a flying ship the appearance of which was somewhat like that shown in Fig. 1, by exhausting the air from metal spheres fastened to a boat. The boat was to be equipped with oars and sails for propulsion and guiding. The method in which he purposed to create the vacuum in the spheres consisted of filling them with water, thus driving out the air, then letting the water run out. He thought that if he closed the tap at the proper time, there would be neither air nor water in the spheres. His flying ship was never constructed, for he piously decided that God would never permit such a change in the affairs of men.

The First Flying Machine. In 1781, Meerwein of Baden, Germany, constructed a flying machine, and was the first, perhaps, to intelligently take into account the resistance of the air. He took the wild duck as a basis of calculation, and found that a man and machine weighing together 200 pounds would require a wing surface of from 125 to 130 square feet. It is of interest to note that Lilienthal, who met his death in trying to apply these principles, over one hundred years later found these figures to be correct. Two views of Meerwein's apparatus are shown in Fig. 2. The construction involved two wood frames covered with cloth. The machine weighed 56 pounds and had a surface area of 111 square feet. The operator was fastened in the middle of the under side of the wings, and over a rod by which he worked the wings. His attempts at flight were not successful, as his ideas of the power of a man were in error.

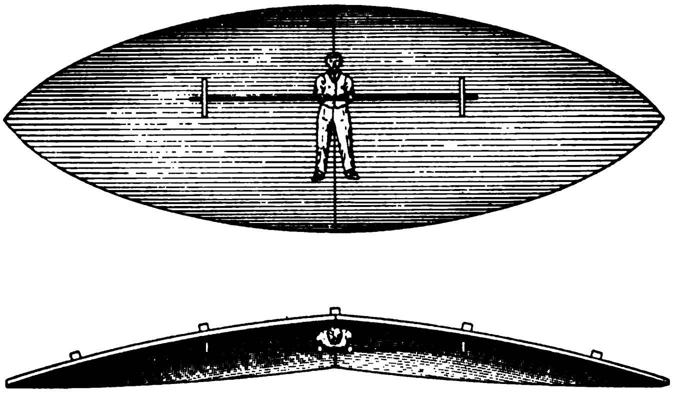


Fig. 2. Meerwein Flying Machine

Classification. All attempts at human flight have gone to show that there are four possible ways in which man may hope to navigate the air. He may imitate the flight of birds with a machine with moving or flapping wings; he may use vertical screws or helices to pull himself up; he may use an aeroplane and sail the air like an eagle; or, lastly, he may raise himself by means of a gas bag and either drift with the wind or move forward by means of propellers.

In these attempts, apparatus of several different types has been developed. The types are classed in two general divisions based on their weight relative to that of the atmosphere, viz, the *lighter-*

than-air machines and the *heavier-than-air machines.* Lighter-than-air machines are those which employ a bag filled with a gas whose specific gravity is sufficiently less than that of the air to lift the bag and the necessary attachments from the earth, and include simple balloons and dirigibles. Heavier-than-air machines, which will neither rise nor remain in the air without motive power, include all forms of aeroplanes.

SIMPLE BALLOONS

Theory. The balloon-like airship has been more highly developed than any other type of aerial craft, probably because it offers the most obvious means of overcoming the force of gravitation. It depends on the law of Archimedes:

"Every body which is immersed in a fluid is acted upon by an upward force, exactly equal to the weight of the fluid displaced by the immersed body."

That is, a body will be at rest if immersed in a fluid of equal specific gravity or equal weight, volume for volume; if the body has less specific gravity than the fluid in which it is immersed it will rise; if it has a greater specific gravity it will sink. Therefore, if the total weight of a balloon is less than the weight of all the air it displaces it will rise in the air. It is, then, necessary to fill the balloon with some gas whose specific gravity is enough less than that of the air to make the weight of the gas itself, the bags, and the attachments, less than the weight of the air displaced by the whole apparatus. The gases usually employed are *hydrogen*, *coal gas*, and *hot air*.

At atmospheric pressure and freezing temperature, the weight of a cubic foot of air is about .08 pound; the weight of a cubic foot of hydrogen is about .005 pound, under the same conditions. According to the law of Archimedes, a cubic foot of hydrogen would be acted upon by a force equal to the difference, or approximately .075 pound, tending to move it upwards. In the same way, a cubic foot of coal gas, which weighs .04 pound, would be acted upon by an upward force of .04 pound.

It is evident, then, that a considerable volume of gas is required to lift a balloon with its envelope, net, car, and other attachments.

Further, it requires almost twice as much coal gas as hydrogen, under the same conditions, for we have seen that the upward force on it is only half as great. The lifting power of hot air is less than one-eighth as great as that of hydrogen at the highest temperature that can possibly be used in a balloon.

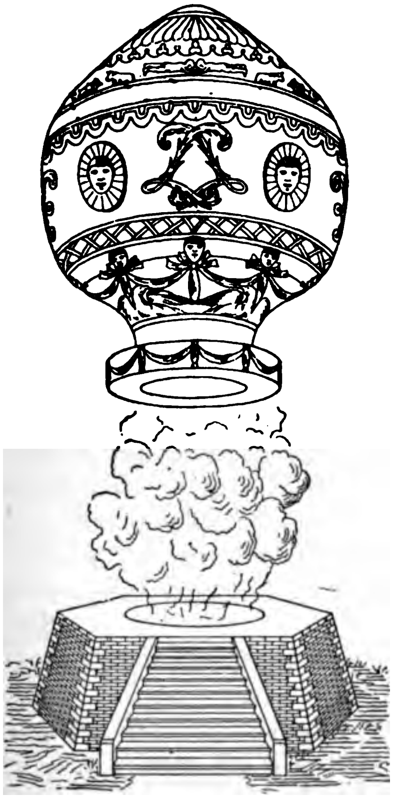


Fig. 3. Montgolfier Balloon

The general type of lighter-than-air machines may be divided into *aerostats* (ordinary balloons, which are entirely dependent on wind currents for lateral movement, and which are often the chief features at country fairs) and dirigible balloons or *aeronats* (air swimmers). Dirigible balloons employ the gas bag for maintaining buoyancy, and have rudders to guide them and propellers to drive them forward through the air in much the same way that ships are driven through the water.

The First Balloon. For several years, Joseph and Steven Montgolfier had been experimenting with a view to constructing a balloon: in the first place by filling bags with *steam;* then by filling bags with *smoke,* and finally by filling bags with *hydrogen.* These attempts were all failures, for the steam rapidly condensed and the smoke and hydrogen leaked through the pores in the bags. They finally hit upon the idea of filling the bag with *hot air,* by means of a fire under its open mouth. Several balloons were burned up, but the next was always made larger, until, at their first public exhibition on June 5, 1783, the bag had become over 35 feet in diameter. On this occasion, it rose to a height of between 900 and 1,000 feet, but the hot air was gradually escaping, and at the end of ten minutes the balloon fell to the ground.

The Montgolfiers then went to Paris, where, after suffering the loss of a paper balloon by rain, they sent up a waterproofed linen one carrying a sheep, a duck, and a rooster in a basket. A rupture in the linen caused the three unwilling aeronauts to make a landing at the end of about ten minutes. The Montgolfiers received great honor, and small balloons of this type became a popular fad. One of these balloons is shown in Fig. 3, making an ascension.

Rozier. The first man to go up in a balloon was Rozier, who ascended in a captive balloon to a height of about 80 feet, in the latter part of the year 1783. Later, in company with a companion, he made a voyage in a free balloon, remaining in the air about half an hour. In these balloons, the air within was kept hot by means of a fire carried in a pan immediately below the mouth of the bag, as shown in Fig. 4. Accidents were numerous on account of the fabric becoming ignited from the fire in the pan.

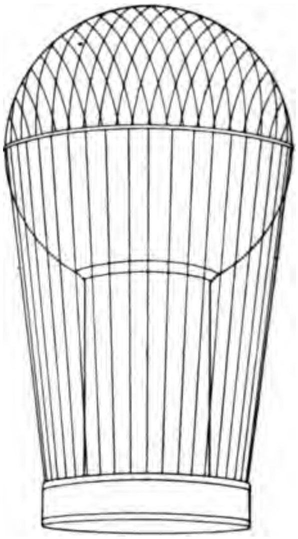


Fig. 4. Rozier Hot-Air Balloon

Improvements by Charles. The physicist, Charles, was working along these lines at the same time. He coated his balloon with a rubber solution to close up the pores, and was thereby enabled to substitute hydrogen for the hot air. Shortly after the Montgolfiers' first public exhibition, Charles sent up his balloon for the benefit of the *Academie des Sciences* in Paris. The balloon, which weighed about 19 pounds, ascended rapidly in the air and disappeared in the clouds, where it burst and fell in a suburb of the city. The impression produced upon the peasants at seeing it fall from the heavens was hardly different from what could be expected. They believed it to be of devilish origin, and immediately tore it into shreds. Charles subsequently built a large balloon quite similar to those in use today. A net was used to support the basket, and a valve, operated by means of ropes from the basket, was arranged at the top to permit the gas to escape as desired.

The Balloon Successful. The English Channel was first crossed in 1785. Blanchard, an Englishman, and Jeffries, an American, started from Dover on January 7 in a balloon equipped with wings and oars. After a very hazardous voyage, during which they had to cast overboard everything movable to keep from drowning, they landed in triumph on the French coast.

An attempt to duplicate this feat was made shortly afterward by Rozier. He constructed a balloon filled with hydrogen, below which hung a receiver in which air could be heated. He hoped to replace by the hot air the losses due to leakage of hydrogen. Soon after the start the balloon exploded, due to the escaping gas reaching the fire, and Rozier and his companion were dashed on the cliffs and killed.

EARLY DIRIGIBLES

Meusnier the Pioneer. The fact that the invention of the dirigible balloon and means of navigating it were almost simultaneous is very little known today and much less appreciated. Like the aeroplane, its development was very much retarded by the lack of suitable means of propulsion, and the actual history of what has been accomplished in this field dates back only to the initial circular flight of La France in 1885. Still the principles upon which success has been achieved were laid down within a year of the appearance of Montgolfier's first gas bag. Lieutenant Meusnier, who subsequently became a general in the French army, must really be credited with being the true inventor of aerial navigation. At a time when nothing whatever was known of the science, Meusnier had the distinction of elaborating at one stroke all the laws governing the stability of an airship, and calculating correctly the conditions of equilibrium for an elongated balloon, after having strikingly demonstrated the necessity for this elongation. This was in 1784 and Meusnier's designs and calculations are still preserved in the engineering section of the French War Office in the form of drawings and tables.

But as often proved to be the case in other fields of research, his efforts went unheeded. How marvelous the establishment of these numerous principles by one man in a short time really is, can be appreciated only by noting the painfully slow process that has been necessary to again determine them, one by one, at considerable intervals and after numerous failures. Through not following the lines which he laid down, aerial navigation lost a century in futile groping about; in experiments absolutely without method or sequence.

Meusnier's designs covered two dirigible balloons and that he fully appreciated the necessity for size is shown by the dimensions of the larger, which unfortunately was never built. This was to be 260 feet long by 130 feet in diameter, in the form of an ellipse, the elongation being exactly twice the diameter. In other words, a perfect ellipsoid, which was a logical and, in fact, the most perfect development of the spherical form. Although increased knowledge of wind resistance and the importance of the part it plays has proved his relative dimensions to be faulty, a study of the principal features of his machine shows that he anticipated the present-day dirigible of the most successful type at practically every point, barring, of course, the motive power, as there was absolutely nothing available in that day except human effort. As the latter weighs more than one-half ton per horse-power, it goes without saying that Meusnier's balloon would have been dirigible only in a dead calm.

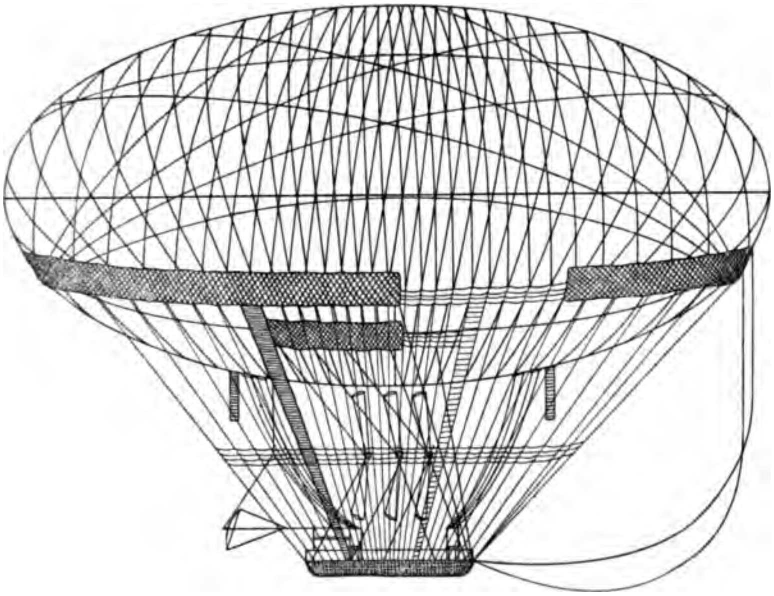


Fig. 5. Meusnier Dirigible Balloon

He adopted the elongated form, conceived the girth fastening, the triangular or indeformable suspension, the air balloonet and its pumps, and the screw propeller, all of which are to be found in the dirigibles of present-day French construction, Fig. 5. It need scarcely be added that the French have not only devoted a greater amount of time and effort to the development of the dirigible than any other nation, but have also met with the greatest success in its use. It was not until 1886, or more than a century after Meusnier had first elaborated those principles, that their value became known. They were set forth by Lieutenant Letourne, of the French engineers, in a paper presented to the *Academie des Sciences* by General Perrier.

In one form or another, the salient features of Meusnier's dirigible will be found embodied in the majority of attempts of later days. His large airship was designed to consist of double envelope, the outer container of which was to provide the strength necessary, and it was accordingly reinforced by bands. The inner envelope was to provide the container for the gas and was not called upon to support any weight. This inner bag or balloon proper was designed to be only partially inflated and the space between the two was to be occupied by air which could be forced into it at two points at either end, by pumps, so as to maintain the pressure on the gas bag uniform regardless of the expansion or contraction of its contents. Here in principle was the air balloonet of today. Instead of employing a net to hang the car from the outer envelope, the former was attached by means of a triangular suspension system fastened to a heavy rope band, or girth, encircling the outer envelope. At the three points where the lifting rope members met, a shaft running the length of the car and carrying what Meusnier described as "revolving oars" was installed. These constituted the prototype of the screw propeller, invented for aerial navigation at a time long antedating the use of steam for marine use. Thus he devised: (1) The air balloonet to husband the gas supply and thus prevent the deformation of the outer container or support, as well as to provide stability; (2) the triangular suspension to attain longitudinal stability; and (3) the screw propeller for propulsion, beside selecting the proper location for the latter.

PROBLEMS OF THE DIRIGIBLE

Ability to Float. If ability to rise in the air depended merely upon a knowledge of the principle that made it possible, it undoubtedly would have been accomplished many centuries ago. As already mentioned, Archimedes established the fact that a body upon floating in a fluid displaces an amount of the latter equal in weight to the body itself, and upon this theory was formulated the now well-known law, that every body plunged into a fluid is subjected by this fluid to a pressure from below, equivalent to the weight of the fluid displaced by the body. Consequently, if the weight of the latter be less than that of the fluid it displaces, the body will float. It is by reason of this that the iron ship floats and the fish swims in water. If the weight of the body and the displaced water be the same, the body will remain in equilibrium in the water at a certain level, and if that of the body be greater, it will sink. All three of these factors are found in the fish, which, with the aid of its natatory gland, can rise to the surface, sink to the bottom, or remain suspended at different levels. To accomplish these changes of specific gravity, the fish fills this gland with air, dilating it until full, or compressing and emptying it. In this we find a perfect analogy to the air balloonet of the dirigible, which serves the same purposes. The method by which lifting power is obtained in the dirigible is exactly the same as in the case of the balloon.

But once in the air, a balloon is, to all intents and purposes, a part of the atmosphere. There is absolutely no sensation of movement, either vertically or horizontally. The earth appears to drop away from beneath and to sweep by horizontally, and regardless of how violently the wind may be blowing, the balloon is always in a dead calm because it is really part of the wind itself and is traveling with it at exactly the same speed. If it were not for the loss of lifting power through the expansion and contraction of the gas, making it necessary to permit its escape in order to avoid rising to inconvenient heights on a very warm day, and the sacrifice of ballast to prevent coming to earth at night, the ability of a balloon to stay up would be limited only by the endurance of its crew and the quantity of provisions it was able to transport. As the use of air balloonets in the dirigible takes care of this, the question of lifting power presents no particular difficulty. It is only a matter of providing sufficient gas to support the increased weight of the car, motor and its accessories, and the crew of the larger vessel, with a factor of safety to allow for emergencies, in order to permit of staying in the air long enough to make a protracted voyage.

Air Resistance vs. Speed. Unless a voyage is to be governed in its direction entirely by the wind, the dirigible must possess a means of moving contrary to the latter. The moment this is attempted, resistance is encountered, and it is this resistance of the air that is responsible for the chief difficulties in the design of the dirigible. To drive it against the wind, it must have power; to support the weight of the motor necessary, the size of the gas bag must be increased. But with the increase in size, the amount of resistance is greatly multiplied and the power to force it through the air must be increased correspondingly. The law is approximately as follows:

Where the surface moves in a line perpendicular to its plane, the resistance is proportional to the extent of the surface, to the square of the speed with which the surface is moved through the air, and to a coefficient, the mean value of which is 0.125.

This coefficient is a doubtful factor, the figure given having been worked out years ago in connection with the propulsion of sailing vessels. Its value varies according to later experimenters between .08 and .16, the mean of the more recent investigations of Renard, Eiffel, and others who have devoted considerable study to the matter, being .08. This is dwelt upon more in detail under "Aerodynamics" and it will be noted that the values of the coefficient K, given here, do not agree with those stated in that article. They serve, however, to illustrate the principles in question.

In accordance with this law, doubling the speed means quadrupling the resistance of the air. For instance, a surface of 16 square feet moving directly against the air at a speed of 10 feet per second will encounter a resistance of 16×100 (square of the speed) $\times 0.125 = 200$ pounds pressure. Doubling the speed, thus bringing it up to 20 feet per second, would give the equation $16 \times 400 \times 0.125 = 800$ pounds pressure, or with the more recent value of the coefficient of .08, 512 pounds pressure. The first consideration is accordingly to reduce the amount of surface moving at right angles. The resistance of a surface having tapering sides which cut through or divide the molecules of air instead of allowing them to impinge directly upon it, is greatly diminished; hence, Meusnier's principle of elongation. If we take the same panel presenting 16 square feet of surface and build out on it a hemisphere, its resistance at a speed of 10 feet per second will be exactly half, or a pressure of 100 pounds.

By further modifying this so as to represent a sharp point, or acute-angled cone, it will be 38 pounds. There could accordingly be no question of attempting to propel a spherical balloon.

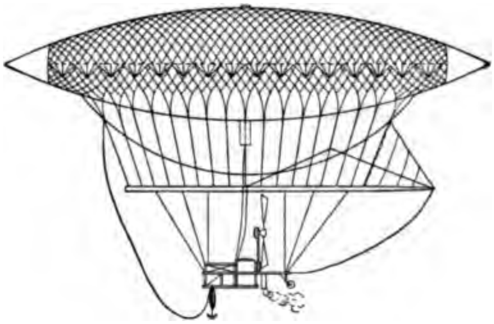


Fig. 6. Giffard Dirigible

It is necessary to select a form that presents as small a surface as possible to the air as the balloon advances, while preserving the maximum lifting power. But experience has strikingly demonstrated the analogy between marine and aerial practice—not only is the shape of the bow of the vessel of great importance but, likewise, the stern. The profile of the latter may permit of an easy reunion of the molecules of air separated by the former, or it may allow them to come together again suddenly, clashing with one another and producing disturbing eddies just behind the moving body. To carry the comparison with a marine vessel a bit further, the form must be such as to give an easy "shear," or sweep from stem to stern.

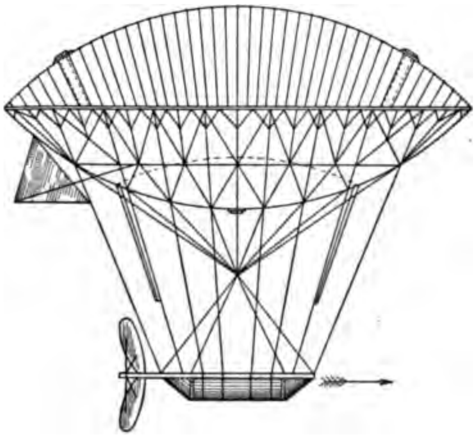


Fig. 7. De Lôme Dirigible

That early investigators appreciated this is shown by the fact that Giffard in 1852, Fig. 6, De Lôme in 1872, Fig. 7, Tissandier in 1884, and Santos-Dumont in his numerous attempts, adopted a spindle-shaped or "fusiform" balloon. In other words, their shape, equally pointed at either end, was symmetrical in relation to their central plan. However, that the shape best adapted to the requirements of the bow did not serve equally well for the stern, was demonstrated for the first time by Renard, to whom credit must be given for a very large part of the scientific development of the dirigible. Almost a century earlier, Marey-Monge had laid down the principle that to be successfully propelled through the air, the balloon must have "the head of a cod and the tail of a mackerel." Nature exemplifies the truth of this in all swiftly moving fishes and birds. Renard accordingly adopted what may best be termed the "pisciform" type, viz, that of a dissymmetrical fish with the larger end serving as the bow; and the performances of the Renard, Lebaudy, and Clement-Bayard airships have shown that this is the most advantageous form.

The pointed stern prevents the formation of eddies and the creation of a partial vacuum in the wake which would impose additional thrust on the bow. Zeppelin has disregarded this factor by adhering to the purely cylindrical form with short hemispherical bow and stern, but it is to be noted that while other German investigators originally followed this precedent, they have gradually abandoned it, owing to the noticeable retarding effect.

Critical Size of Bag. Next in importance to the best form to be given the vessel, is the most effective size—something which has a direct bearing upon its lifting power. This depends upon the volume, while the resistance is proportional to the amount of surface presented. Greater lifting power can accordingly be obtained by keeping the diameter down and increasing the length. But the resistance is also proportionate to the square of the speed, while the volume, or lifting power, varies as the cube of the dimensions of the container, so that in doubling the latter, the resistance of the vessel at a certain speed is increased only four times while its lifting capacity is increased eight times. Consequently the larger dirigible is very much more efficient than the smaller one since it can carry so much more weight in the form of a motor and fuel in proportion to its resistance to the air. As an illustration of this, assume a rectangular container with square ends 1 foot each way and 5 feet long. Its volume will be 5 cubic feet and if the lifting power of the gas be assumed as 2 pounds per cubic foot, its total lifting power will be 5 pounds. If a motor weighing exactly 5 pounds per horse-power be assumed, it will be evident that the motor which such a balloon could carry would be limited to 1 horse-power, neglecting the weight of the container.

Double these dimensions and the container will then measure 2×2×10 feet, giving a volume of 40 cubic feet, and a lifting power, on the basis already assumed, of a motor capable of producing 8 horse-power, and this without taking into consideration that as the size of the motor increases, its weight per horse-power decreases. The balloon of twice the size will thus have a motor of 8 horse-power to overcome the resistance of the head-on surface of 4 square feet, or 2 horse-power per square foot of transverse section, whereas the balloon of half the size will have only 1 horse-power per square foot of transverse section. It is, accordingly, not practicable to construct small dirigibles such as the various airships built by Santos-Dumont for his experiments, while, on the other hand, there are numerous limitations that will be obvious, restricting an increase in size beyond a certain point, as has been shown by the experience of the various Zeppelin airships.

To make it serviceable, what Berget terms the "independent speed" of a dirigible, *i.e.*, its power to move itself against the wind, must be sufficient to enable it to travel under normally prevailing atmospheric conditions. These naturally differ greatly in different countries and in different parts of the same country. Where meteorological tables showed the prevailing winds in a certain district to exceed 15 miles an hour throughout a large part of the year, it would be useless to construct an airship with a speed of 15 miles an hour or less for use in that particular district, as the number of days in the year in which one could travel to and from a certain starting point would be limited. This introduces another factor which has a vital bearing upon the size of the vessel. Refer to the figures just cited and assume further that by doubling the dimensions and making the airship capable of transporting a motor of 8 horse-power, it has a speed of 10 miles an hour. It is desired to double this. But the resistance of the surface presented increases as the square of the speed. Hence, it will not avail merely to double the power of the motor. Experience has demonstrated that the power necessary to increase the speed of the same body, increases in proportion to the cube of the speed, so that instead of a 16-horse-power motor in the case mentioned, one of 64 horse-power would be needed. There are, accordingly, a number of elements that must be taken into consideration when determining the size as well as the shape of the balloon.

Fabric and Color. As the gas is frequently under considerable pressure when the balloon expands under the influence of the suns' heat, a great deal of experiment has been necessary to find the best class of fabric for the making of the envelope. Under the pressure, an ordinary fabric would stretch and permit the escape of a large percentage of the gas. It has been found impossible to weave any fabric that will be close enough to hold hydrogen under pressure, so that recourse is had to a combination of cloth and rubber. The cloth is an extremely fine weave of cotton even lighter and closer than the best of racing yacht duck, and it is combined with rubber under heavy pressures. Three layers of this rubberized fabric are cemented together to form what is known as "balloon cloth," which is about as impermeable a material as can be made without involving undue weight. The necessity of using rubber in it has introduced a complication, it having been found by experiment that rubber is strongly attacked by the ultra-violet rays of sunlight, which probably accounts for the fact that balloon envelopes are usually found more or less damaged after a high ascension, the influence of these rays being much greater at the higher altitudes. To offset this, experiments are being made in the introduction of coloring matter in the fabric, some envelopes having been dyed yellow and others red. M. Reynaud, who has conducted a series of experiments illustrating the damage suffered by rubber when subjected to the light of a mercury vapor lamp with a quartz tube, which is a powerful source of such rays, recommends red as absorbing both the violet and blue rays.

Static Equilibrium. Having settled upon the size and shape, there must be an appropriate means of attaching the car to carry the power plant, its accessories and control, and the crew. While apparently a simple matter, this involves one of the most important elements of the design—that of stability. A long envelope of comparatively small diameter being necessary for the reasons given, it is essential that this be maintained with its axis horizontal. In calm air, the balloon, or container, is subjected to the action of two forces: One is its weight, applied to the center of gravity of the system formed by the balloon, its car, and all the supports; the other is the thrust of the air, applied at a point known as the center of thrust and which will differ with different designs, according as the car is suspended nearer or farther away from the balloon. If the latter contained only the gas used to inflate it, with no car or other weight to carry, the center of gravity and the center of thrust would coincide, granting that the weight of the envelope were negligible. As this naturally can not be the case, these forces are not a continuation of each other. But as they must necessarily be equal if the balloon is neither ascending nor descending, it follows that they will cause the balloon to turn until they are a continuation of each other, and in the case of a pisciform balloon, this will cause it to tilt downward. Like a ship with too much cargo forward, it would be what sailors term "down at the head."

As this would be neither convenient nor compatible with rapid propulsion, it must be avoided by distributing the weight along the car in such a manner that when the balloon is horizontal, the forces represented by the pressure above and the weight below, must be in the same perpendicular. This is necessary to insure *static equilibrium*, or a horizontal position while in a state of rest. To bring this about, the connections between the car and the balloon must always maintain the same relative position, which is further complicated by the fact that they must be flexible at the same time.

Longitudinal Stability. But the *longitudinal stability* of the airship as a whole must be preserved, and this also involves its *stability of direction.* Its axis must be a tangent to the course it describes, if the latter be curvilinear, or parallel with the direction of this course where the course itself is straight. This is apparently something which should be taken care of by the rudder, any tendency on the part of the airship to diverge from its course being corrected by the pilot. But a boat that needed constant attention to the helm to keep it on its course would be put down as a "cranky" —in other words, of faulty design in the hull. A dirigible having the same defect would be difficult to navigate, as the rudder alone would not suffice to correct this tendency in emergencies. Stability of direction is, accordingly, provided for in the design of the balloon itself, and this is the chief reason for adopting the form of a large-headed and slender-bodied fish, as already outlined. This brings the center of gravity forward and makes of the long tail an effective lever which overcomes any tendency of the ship to diverge from the course it should follow, by causing the resistance of the air itself to bring it back into line. However, the envelope of the balloon itself would not suffice for this, so just astern of the latter, "stabilizing surfaces"are placed,consisting of vertical planes fixed to the envelope. These form the keel of the dirigible and are analogous to the keel of the ship. Stability of direction is thus obtained naturally without having constant recourse to the rudder, which is employed only to alter the direction of travel.

The comparison between marine and aerial navigation must be carried even further. These vertical planes, or "keel," prevent rolling; it is equally necessary to avoid pitching—far more so than in the case of a vessel in water. So that while the question of stability of direction is intimately connected with longitudinal stability, other means are required to insure the latter. The airship must travel on an "even keel," except when ascending or descending, and the latter must be closely under the control of the pilot, as otherwise the balloon may incline at a dangerous angle. This shows the importance of an unvarying connection between the car and the envelope to avoid defective longitudinal stability. Assume, for instance, that the car is merely attached at each end of a single line. The car, the horizontal axis of the balloon, and the two supports would then form a rectangle. When in a state of equilibrium the weight and the thrust are acting in the same line. Now suppose that the pilot desires to descend and inclines the ship downward. The center of gravity is then shifted farther forward and the two forces are no longer in line.

But as the connections permit the car to swing in a vertic
plane, they permit the latter to move forward and parallel with t
balloon, thus forming a parallelogram instead of a rectangle. T
causes the center of gravity to shift even farther, and as one of t
most serious causes of longitudinal stability is the movement of
gas itself, it would also rush to the back end and cause the ball
to "stand on its head." As the tendency of the gas is thus to
ment any inclination accidentally produced, the vital necessit
providing a suspension that is incapable of displacement with
tion to the balloon is evident. Here is where the importance of
nier's conception of the principle of triangular suspension com
Instead of being merely supported by direct vertical conne
with the balloon, the ends of the car are also attached

opposite ends of the envelope, forming opposite triangles. This gives an unvarying attachment, so that when the balloon inclines, the car maintains its relative position, and the weight no longer being a prolongation of the thrust, the two forces tend to pull each other back in the same line, or, in other words, to "trim ship." Granting a proper form of balloon or gas container to start with, it will be evident that due attention to the principles just outlined will produce a vessel that will not only hold to its course without fatiguing the pilot, but that will also not be subject to a tendency to pitch or roll. As air is much easier to displace than water, it will be evident that either of these characteristics would be far more dangerous in an airship than in a marine vessel and they would naturally be sufficient to condemn it, even in the absence of other shortcomings.

Dynamic Equilibrium. In addition to being able to preserve its static equilibrium and to possess proper longitudinal stability, the successful airship must also maintain its *dynamic equilibrium*—the equilibrium of the airship in motion. This may be made clear by referring to the well-known expedients adopted to navigate the ordinary spherical balloon. To rise, its weight is diminished by gradually pouring sand from the bags which are always carried as ballast. To descend, it is necessary to increase the total weight of the balloon and its car, and the only method of accomplishing this is to permit the escape of some of the gas, the specific lightness of which constitutes the lifting power of the balloon. As the gas escapes, the thrust of the air on the balloon is decreased and it sinks—the ascensional effort diminishing in proportion to the amount of gas that is lost. The balloon, or the container itself, being merely a spherical bag, on the upper hemispherical half of which the net supporting the car presses at all points, the question of deformation is not a serious one. Before it assumed proportions where the bag might be in danger of collapsing, the balloon would have had to come to earth through lack of lifting power to longer sustain it. Owing to its far greater size, as well as to the form of the surface which it presents to the air pressure, such a crude method is naturally not applicable to the dirigible.

Dynamic equilibrium must take into account not only its weight and the sustaining pressure of the air, but also the resistance of the air exerted upon its envelope. This resistance depends upon the dimensions and the shape of that envelope, and in calculations the latter is always assumed to be invariable. Assume, for instance, that to descend the pilot of a dirigible allowed some of the hydrogen gas to escape. As the airship came down, it would have to pass through strata of air of constantly increasing pressure as the earth is approached. The reason for this will be apparent as the lower strata bear the weight of the entire atmosphere above them. The confined gas will no longer be sufficient to distend the envelope, the latter losing its shape and becoming flabby. As the original form is no longer retained, the center of resistance of the air will likewise have changed together with the center of thrust, and the initial conditions will no longer obtain. But as the equilibrium of the airship depends upon the maintenance of these conditions, it will be lost if they vary.

Function of Balloonets. In the function of balloonets is realized the importance of the principle established by Meusnier. It was almost a century later before it was rediscovered by Dupuy de Lôme in connection with his attempts to make balloons dirigible. That the balloon must always be maintained in a state of perfect inflation has been pointed out. But gas is lost in descents and to a certain extent, through the permeability of the envelope. Unless it is replaced, the balloon will be only partially inflated. In view of the great volume necessary, it requires no explanation to show that it would be impossible to replace the gas itself by fresh hydrogen carried on the car. It would have to be under high pressure and the weight of the steel cylinders as well as the number necessary to transport a sufficient supply would be prohibitive. Hence, Meusnier conceived the idea of employing air. But this could not be pumped directly into the balloon to mix with the hydrogen gas, as the resulting mixture would not only still be as inflammable as the former alone, but it would also contain sufficient oxygen to create a very powerful and infinitely more dangerous explosive. This led to the adoption of the *air balloonet.*

In principle the balloonet consists of dividing the interior of the envelope into two cells, the larger of which receives the light gas while the smaller is intended to hold air and terminates in a tube extending down to a pump in the car. In other words, a fabric partition adjacent to the lower part of the envelope inside and subject to deformation at will. In actual practice it consists of a number of independent cells of this kind, longitudinally disposed along the lower half of the interior of the envelope, as in the case of Wellman's "America," which was equipped with a number of air balloonets, the location of which may be noted by referring to the illustrations of this airship, Fig. 19.

When the balloon is completely inflated with hydrogen, as at the beginning of an ascent, these balloonets lie flat against the lower part of the envelope, exactly like a lining. As the airship rises, the gas expands owing to the reduction in atmospheric pressure at a higher altitude, as well as to the influence of heat. With the increase in pressure, uniform inflation is maintained by the escape of a certain amount of gas through the automatic valves provided for the purpose. Unless this took place, the internal pressure might assume proportions placing the balloon in danger of blowing up. To avoid this, a pressure gauge communicating with the gas compartment is one of the most important instruments on the control board of the car, and should its reading indicate a failure of the automatic valves, the pilot must reduce the pressure by operating a hand valve. But as the car descends, the increased external pressure causes a recontraction of the gas until it no longer suffices to fill the envelope. To replace the loss the air pumps are utilized to force air into the air balloonets until the sum of the volumes of gas and air in the different compartments equals the original volume. In this manner, the initial conditions, upon which the equilibrium of the airship is based, are always maintained.

This is not the only method of correcting for change in volume, nor of maintaining the longitudinal stability of the whole fabric, the importance of which has already been detailed, but experience has shown that it is the most practical. It is possible to give the balloon a rigid frame over which the envelope is stretched and to attach the car by means of a rigid metal suspension, as in the various Zeppelin airships, or to take it semi-rigid, as in the Gross, another German type in which Zeppelin's precedent was followed only in the case of the suspension. To prevent deformation by this means, the balloon is provided with an absolutely rigid skeleton of aluminum tubes. This framing is in the shape of a number of uniform cylindrical sections, or gas compartments, each one of which accommodates an independent balloon, while over the entire frame a very strong but light fabric constituting the outer or protecting envelope is stretched taut. The idea of the numerous independent balloons is to insure a high factor of safety as the loss of the entire contents of two or three of them through accident would not dangerously affect the lifting power of the whole. Apart from its great expense, the rigid nature of this construction makes it a delicate thing to handle on the ground, as witness the numerous wrecks that have attended the landings of the huge, non-flexible mass. To minimize this risk in starting, its "home port" had to be made in the form of a floating shed, anchored only at one end so that the ship could always emerge to "leeward."

The system of air balloonets has accordingly been adopted by every other designer, in variously modified forms, as illustrated by the German dirigible Parseval, in which but two air bags were employed, one at either end. They were interconnected by an external tube to which the air-pump discharge was attached, and were also operated by a counterbalancing system inside the gas bag, by means of which the inflation of one balloonet, as the after one, for example, caused the collapse of the other.

Influence of Fish Form of Bag. But a condition of dynamic equilibrium can not be obtained with the combined aid of the precautions already noted to secure longitudinal stability and that of the air balloonet in maintaining uniform inflation. Why this is so will be clear from a simple example. If a simple fusiform or spindle-shaped balloon be suspended in the air in a horizontal plane, the axis of which passes through its center of gravity, it would be practically pivoted on the latter and would be extremely sensitive to influences tending to tilt it up or down. It would be in a state of "indifferent" longitudinal equilibrium. As long as the axis of the balloon remains horizontal and the air pressure is coincident with that axis, it will be in equilibrium, but an equilibrium essentially unstable. Experiment proves that the moment the balloon inclines from the horizontal in the slightest degree, there is a strong tendency for it to revolve about its center of gravity until it stands vertical to the air current, or is standing straight up and down. This, of course, refers to the balloon alone without any attachments. Such a tendency would be fatal, amounting as it does to absolute instability.

If instead of symmetrical form, tapering toward both ends, a pisciform balloon be tried, it will still evidence the same tendency, but in greatly diminished degree. This is not merely the theory affecting its stability but represents the findings of Col. Charles Renard, who undoubtedly did more to formulate the exact laws governing the stability of a dirigible than any other investigator in this field. His data is the result of a long and methodically carried out series of experiments. In the case of the pisciform balloon, the disturbing effect is due in unequal degree, to the diameter of the balloon and its inclination and speed, whereas the steadying effect depends upon the inclination and diameter, but not on the speed. The disturbing effect, therefore, depends solely on the speed and augments very rapidly as the speed increases. It will, accordingly, be apparent that there is a certain speed for which the two effects are equal, and beyond which the disturbing influence, depending on speed, will overcome the steadying effect.

To this rate of travel, Renard applied the term "critical speed," and when this is exceeded the equilibrium of the balloon becomes unstable. To obtain this data, keels of varying shapes and dimensions were submitted to the action of a current of air, the force of which could be varied at will. In the case of the La France, the first fish-shaped dirigible, the critical speed was found to be 10 meters, or approximately 39 feet per second, a speed of 21.6 miles per hour, and a 24-horse-power motor suffices to drive the airship at this rate of travel. But the internal combustion motor is now so light that a dirigible of this type could easily lift a motor capable of generating 80 to 100 horse-power. With this amount of power, its theoretic speed would be 50 per cent greater, or 33 miles an hour. But this could not be accomplished in practice as long before it was reached the stability would become precarious. As Colonel Renard observed in the instance just cited, "If the balloon were provided with a 100-horse-power motor, the first 24 horse-power would make it go and the other 76 horse-power would break our necks."

Steadying Planes. It is accordingly necessary to adopt a further expedient to insure stability. This takes the form of a system of rigid planes, both vertical and horizontal, located in the axis of the balloon and placed a considerable distance to the rear of the center of gravity. With this addition, the resemblance of the after end of the balloon to the feathering of an arrow is apparent, while its purpose is similar to that of the latter. For this reason, these steadying planes have been termed the *empennage,* which is the French equivalent of "arrow feathering," while its derivative *empennation* is employed to describe the counteraction of this disturbing effect. In the La France, which measured about 230 feet in length by 40 feet in diameter, the area of the planes required to accomplish this was 160 square feet, and the planes themselves were placed almost 100 feet to the rear of the center of gravity. By referring to the illustrations of the various French airships, the various developments in the methods of accomplishing this will be apparent.

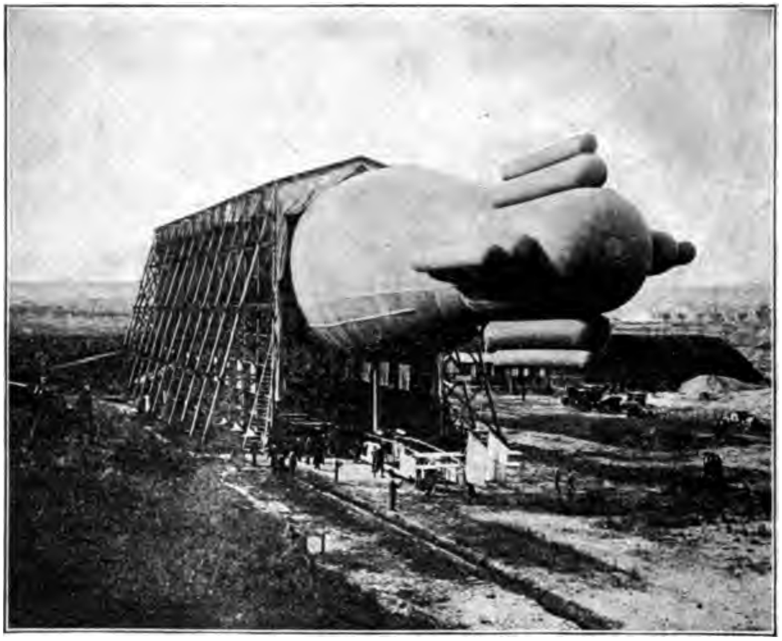


Fig. 8. La Ville de Paris Showing Balloonets

In the Lebaudy balloon, it took the form of planes attached to the framework between the car and the balloon. In La Patrie and La Republique, the resemblance to the feathered arrow was completed by attaching four planes in the form of a cross directly to the stern of the balloon itself. But as weight, no matter how slight, is a disturbing factor at the end of a long lever, such as is represented by the balloon, Renard devised an improvement over these methods by conceiving the use of hydrogen balloonets as steadying planes. This idea was first embodied in La Ville de Paris, Fig. 8, in the form of cylindrical balloonets, and as conical balloonets on the Clement-Bayard. These balloonets communicate with the gas chamber proper of the balloon and consequently exert a lifting pressure which compensates for their weight, so that they no longer have the drawback of constituting an unsymmetrical supplementary load. Zeppelin provides for dynamic stability by the use of an extremely long car along the length of which a considerable weight in concentrated form may be displaced to counteract any tendency to tilt. This, however, has the disadvantage of placing a great and comparatively useless additional burden on the lifting power of the car, and is neither simple nor automatic in its action, as is the *empennage*.

Location of Propeller. The final factor of importance in the design of the successful dirigible, is the proper location of the propulsive effort with relation to the balloon. Theoretically, this should be applied to the axis of the balloon itself, as the latter represents the greater part of the resistance offered to the air. At least one attempt to carry this out in practice resulted disastrously, that of the Brazilian airship Pax, while the form adopted by Rose in which the propeller was placed between the twin balloons in a plane parallel with their horizontal axes, was not a success. In theory, the balloon offers such a substantial percentage of the total resistance to the air that the area of the car and the rigging were originally considered practically negligible by comparison. Actually, however, this is not the case. Calculation shows that in the case of any of the typical French airships mentioned, the sum of the surface of the suspending rigging alone is easily the equivalent of 2 square meters, or about 21 square feet, without taking into consideration the numerous knots, splices, pulleys, and ropes employed in the working of the vessel, air tubes communicating with the air balloonets, and the like. Add to this equivalent area that of the passengers, the air pump, other transverse members and exposed surfaces, and the total will be found equivalent to a quarter or even a third of the transverse section of the balloon itself.

To insure the permanently horizontal position of the ship under the combined action of the motor and the air resistance, a position of the propeller at a point about one-third of the diameter of the balloon below its horizontal axis will be necessary. Without employing a rigid frame like that of the Zeppelin and the Pax, however, such a location of the shaft is a difficult matter for constructional reasons. Consequently, it has become customary to apply the driving effort to the car itself, as no other solution of the problem is apparent. This accounts for the tendency common in the dirigible to "float high forward," and this tilting becomes more pronounced in proportion to the distance the car is hung beneath the balloon. The term "deviation" is employed to describe this tilting effect produced by the action of the propeller. Conflicting requirements are met with in attempting to reduce this by bringing the car closer to the balloon as this approximation is limited by the danger of operating the gasoline motor too close to the huge volume of inflammable gas. The importance of this factor may be appreciated from the fact that if the car were placed too far from the balloon, the propulsive effect would tend to hold the latter at an angle without advancing much, owing to the vastly increased air resistance of the much larger surface thus presented. The best solution of the problem has been found by placing the motor in the car and driving a shaft located between the car and the balloon by means of a chain.

This has not been very generally followed, however, owing to the different ideas prevailing as to the best location for the propeller itself. In the Ville de Paris and the Clement-Bayard, it is placed at the bow and serves to draw the balloon along. Earlier attempts, such as Giffard's, De Lôme's, and the Tissandier airship, patterned after marine practice by placing it at the stern. The constructor of the Lebaudy and La Patrie adopted the use of two propellers, placed on either side of the car and almost in a line with its center, this also being the case in the design of the America, except that the latter was provided with four screws altogether, two of which were on swiveling joints to allow of their being utilized to either drive the ship ahead, or to assist in its ascent or descent by being driven at right angles to their shaft. Zeppelin also employs four propellers placed along the sides of the car. The United States army dirigible has the screw forward, while the British military airship carries it at the stern of a very short car. On the whole, its location at the bow would appear to offer the greatest advantage, where a single propeller is employed.

Relations of Speed and Radius of Travel. The various factors influencing the speed of a dirigible have already been referred to, but it will be apparent that the radius of action is of equally great importance. It is likewise something that has a very direct bearing upon the speed and, in consequence, upon the design as a whole. It will be apparent that to be of any great value for military or other purposes, the dirigible must possess not only sufficient speed to enable it to travel to any point of the compass under ordinarily prevailing conditions of wind and weather, but it must likewise be able to remain in the air for some time and cover considerable distance under its own power. In fact, one of the chief advantages possessed by the dirigible over the aeroplane at present is its ability to make long-sustained flights, while carrying a comparatively large crew and a great deal of extra weight.

Total Weight per Horse-Power Hour. As is the case in almost every point in the design of the dirigible, conflicting conditions must be reconciled in order to provide it with a power plant affording sufficient speed with ample radius of action. It has already been pointed out that power requirements increase as the *cube of the speed,* making a tremendous addition necessary to the amount of power to obtain a disproportionately small increase in velocity. In this connection thereis a phase of the motor question that has not received the attention it merits up to the present time. The struggle to reduce weight to the attainable minimum has made *weight per horse-power* apparently the paramount consideration—a factor to which other things could be sacrificed. And this is quite as true of the aeroplane motor as those designed for use in the dirigible. But it is quite as important to make the machine go as it is to raise it in the air, so that the question of *total weight per horse-power hour* will undoubtedly come in for much more attention in future, particularly since weight per horse-power appears to have approached so closely the minimum attainable, consistent with a due regard for reliability.

The relative importance of these two factors may be appreciated from the following illustration:

Assume, for instance, a 100 horse-power motor of a total weight of 1,000 pounds, round numbers being chosen merely for the sake of simplicity. The weight per horse-power of such an engine would be 10 pounds. This would not be sufficient data, however, from which the design of a dirigible to employ that motor could be worked out. *Pounds per horse-power* usually refers to a bare engine. The weight of cooling water, lubricants, accessories, and last, but far from least, that of the fuel, must be added. For example, the motor referred to may be assumed to require 1 pound of fuel and lubricant per horse-power per hour to run it at its normal output—*i. e.*, 100 horse-power. This means that it will consume 100 pounds per hour, or for a run of 10 hours, 1,000 pounds, and this weight must be added to that of the motor itself in considering the design from the standpoint of radius of action. On the above basis, 1,000 horse-power hours will be obtainable, and dividing the total weight of motor and supplies (2,000 pounds) by this, would give a weight of 2 pounds per horse-power hour.

This factor depends entirely upon the efficiency of the motor, while *its* weight per horse-power is a question of its construction alone. It requires no abstruse calculations to show that it is quite possible to have the same number of pounds for the weight per horse-power of a very light engine that consumes a great deal of fuel, as it is with a heavy engine that consumes very little. The diminution of the weight per horse-power hour makes possible an increase in the duration of the voyage, which is a very desirable advantage, but as the prime factor is ability to rise, improvement that involves the addition of the weight is closely restricted by the lifting power available, so that radius of action is governed by numerous considerations, as will be seen from the following:

Take a dirigible with a gas capacity of 12,000 cubic feet, equipped with two 60-horse-power motors, giving it a speed of 36 miles per hour. The engines will consume 130 pounds of fuel per hour, and the machine, with 6 passengers, will have sufficient lifting capacity to carry 1,300 pounds of gasoline. This would mean traveling for 10 hours, or 5 hours in each direction, if necessary to return to the starting point as is usually the case. This would mean traveling 180 miles from the start—in other words, the radius of action of this dirigible would be 180 miles. But this is based on traveling at maximum speed for the entire period, disregarding the prevailing winds, the influence of which will be taken up later. War vessels seldom steam for any length of time at full speed, except in emergencies. They run under reduced power, or at a "cruising speed," thus greatly extending their available radius of action. The same thing may be done with the dirigible. By using only one of the motors of the airship in question, the period for which it could travel would be doubled. The propelling power will be then only 60 horsepower. The speed will be divided by the cubic root of 2, bringing it down to approximately 29 miles an hour. But as the single motor will consume only 65 pounds of fuel per hour, it will have 20 hours of travel, or 10 hours to go and 10 to return, so that its radius of action will be 290 miles. The importance of this in the application of aerial navigation to military service will be plain.

Speed is quite as costly in an airship as it is in an Atlantic liner. To double it, the motor power must be multiplied by 8, and the machine must carry 8 times as much fuel. But by cutting the power in half, the speed is reduced only one-fifth. The problem of long voyages in the dirigible is, accordingly, how to reconcile best the minimum speed which will enable it to effectively make way against the prevailing winds, with the reduction in power necessary to cut the fuel consumption down to a point that will insure a long period of running. From the above discussion, it is evident that at least two independent motors should be provided, so that under favorable weather conditions, only one need be employed, while the total power of both could be called upon in emergencies. This was the expedient adopted in the instance of the America, designed to make a 3,000-mile voyage.

Influence of Wind. But the wind is a serious factor that has to be taken into consideration. Radius of action as above illustrated has been based entirely upon traveling in a dead calm. True, where the prevailing wind blew from a certain quarter for a length of time, its favoring influence in going would be neutralized by its resistance in returning, so that the result would be the same, provided the velocity of the wind were not too great to prevent returning at all against it. But with the perversity of inanimate things, the wind may always be in the wrong direction, or seemingly so. Or again, the strong wind which retards progress on the outgoing trip, may die down to a perfect calm when it is time to return, so that the disadvantage of having to travel against it will not be compensated for by extra speed returning. The wind is something with which the aeronaut must always figure, quite as much as the sailor.

TABLE I

Speed* of the Wind for the Vicinity of Paris

Speed of Wind in Feet per Second	Speed of Wind in Miles per Hour	Number of Days per Year when Velocity might be less than given in the first two columns
10	6.8	39
20	13.6	117
30	20.5	197
40	27.3	258
50	34.1	297
60	40.9	323
70	47.7	342
80	54.6	350
90	61.4	354
100	68.2	358
110	75.	361
120	81.8	363
130	88.7	364
140	95.5	364
150	102.3	364
160	109.1	365
170	116.	365
180	122.8	365

*The above speed values are only approximations to the metric quantities.

When the speed of the dirigible is greater than that of the prevailing wind, it may travel in any direction; when it is considerably less, it can travel only with the wind; when it is equal to the speed of the latter, it may travel at an angle with the wind—in other words, tack, as a ship does, utilizing the pressure of the contrary wind to force the ship against it. But as the air does not offer the same hold on it to the hull of the airship, as water does to that of the seagoing ship, the amount of leeway or drift in such a maneuver would doubtless be excessive. This briefly sums up a subject to which many pages are devoted in the textbooks, and it applies quite as much to the aeroplanes as it does to the dirigible.

As the wind has always been a factor of great importance, carefully compiled meteorological tables accurately indicate the winds that are to be expected on the ocean in any part of the globe at different seasons in the year, giving their direction, average strength, or velocity, and the number of days per year on which certain wind may reasonably be looked for. Data of a similar nature is largely lacking with regard to the land, but now that aerial navigation is so prominently to the fore, it will undoubtedly receive the attention it deserves. In fact, this has already been done for the vicinity of Paris, and likewise in several parts of Germany and Sweden, where accurate observations have been made to determine the possibility of employing wind wheels for power purposes. The importance of such tables to the aeronaut will be apparent. Table I is given by Berget as applying to the vicinity of Paris.

It requires only a superficial study of this table to demonstrate that the vicinity of Paris is a favorable district for the navigation of dirigibles of moderate power and speed. Take an airship having a speed of only 22.3 (36 kilometers) miles per hour as an instance of this. The table shows that there are 258 days in a year when the velocity of the wind is less than 40 feet per second. By increasing this to 27.9 miles per hour (45 kilometers), which is the speed of the Clement-Bayard, the Republique, and Le Ville de Paris, it will be evident that such a balloon would be dirigible on an average of 297 days out of the 365, or about ten months out of the twelve. But, as has been shown by the observations made from the Eiffel Tower, the speed of the wind is very much less near the ground than it is at greater altitudes. In the locality in question, observations indicate that the average velocity of the wind the year round, at the level of the house tops, is between 8 and 10 feet per second, while at the top of the tower, or 1,000 feet from the ground, it is 32 feet. To again refer to the table, it will be seen that by giving an airship an independent speed of slightly over 43 miles per hour, it will be navigable on 350 days out of the year, and as the days on which the wind velocity exceeds 80 feet per second are those of bad storms, in which neither the dirigible nor the aeroplane would be an ideal means of transport, the problem where the former is concerned would appear to find its solution in an increase of its speed to this point. To do this and still provide an effective radius of action with the present percentage of efficiency of the average light motor built for aeronautical use is not an easy matter, particularly as the greatly increased air resistance would also involve a much stronger envelope to stand the high pressure. This means added weight and cuts down the lifting power for the same volume, while increasing the latter means greatly augmented air resistance and greater power to attain the same speed.

FRENCH DIRIGIBLES

The First Lebaudy. The interest evidenced by the German War Department in Zeppelin's airship was more than duplicated by that aroused in French military circles by the success of the Lebaudy Brothers. Since 1900 these two brothers had been experimenting with dirigible balloons. Their first dirigible—built by the engineer Juillot—made thirty flights, in all but two of which it succeeded in returning to its starting point. This machine was somewhat similar to the later types built by Santos-Dumont, and carried a 40-horse-power Daimler motor. A speed of 36 feet per second, or about 25 miles per hour, was obtained. During tests in the summer of 1904, the balloon was dashed against a tree and almost entirely destroyed.

Lebaudy 1904. The next year the "Lebaudy 1904" appeared. This was 190 feet long and had a capacity of 94,000 cubic feet of gas. The air bag was divided into three parts and contained 17,600 cubic feet of air. It was supplied with air from a fan driven by the engine, and an auxiliary electric motor and storage battery were carried to drive the fan when the gas engine was not working. The storage battery was also used to furnish electric lights for the airship. A horizontal sail of silk was stretched between the car and the gas bag. This had an area of something over 1,000 square feet, and a sort of keel of silk was stretched below it. A horizontal rudder, shaped like a pigeon's tail, was used at the rear, and immediately behind it were two V-shaped vertical rudders. A small vertical sail was carried, which could be used to assist in guiding the airship. The car was 16 feet long, and was rigidly hung 10 feet below the bag. It was provided with an inverted pyramid of steel tubes meeting at an apex below the car to prevent injury in alighting. Sixty-three ascents were made in 1904 with this balloon, all of them comparatively successful, the longest being a journey of 60 miles in two hours and forty-five minutes. It was then turned over to the War Department as a school ship.

The next year a new and larger balloon, equipped with a more powerful motor was used. Many flights were made in tests for the

French War Department. In some of these, the Lebaudy Brothers were accompanied by the minister of war.

La Patrie. La Patrie was then built for the French government by the Lebaudy Brothers, and was of the same design as their earlier airships. In speed it was nearly equal to Zeppelin's, and its dirigibility was nearly perfect. Fig. 9 shows a view of this airship in flight.

It was 200 feet long, and the 70-horse-power engine drove two propellers. It could carry seven people and one-half ton of ballast. It carried four people at a speed of 30 miles per hour. On its last trip it covered 175 miles in seven hours. A few days afterward, a heavy wind tore it away from its moorings, and it was blown out to sea and lost.

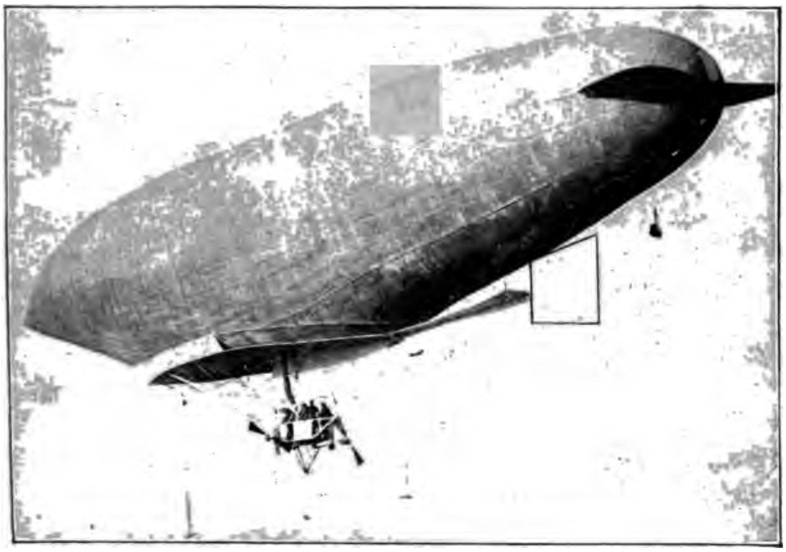


Fig. 9. La Patrie, French War Dirigible

La Republique and Le Jaune. Two more airships of the same type, La Republique and Le Jaune, followed this. These were tried by the French government in 1908, and both proved successful. La Republique is illustrated in Fig. 10. The shape and equipment of the car are shown in Fig. 11. The automobile-type radiator may be seen attached to the side of the car. During a flight in the fall of 1909, a propeller blade broke and was thrown clear through the

Fig. 10. La Republique, French War Dirigible

Fig. 11. Car of La Republique

balloon envelope, causing the balloon to fall from a height of 500 feet. The four officers who formed the crew of the dirigible were instantly killed.

The Russian government commissioned the Lebaudy Brothers to build an airship which was to be the nucleus of the Russian air navy. Accordingly, the Russie was built early in 1909, and is a faithful copy of the French La Republique in every respect; a number of others have been delivered to the Russian army since. Trips are in progress at the Lebaudy Airship Works at Moisson.

Portable Airship. For military purposes, an airship should be so constructed as to be easily and quickly packed. A dirigible balloon was built in 1908 by Count de la Vaulx, which could be very easily taken apart for transportation and put together again. The fact that it was capable of carrying only one man was the cause of its limited usefulness.

Clement-Bayard II. The numerous factors that must be considered in the design of a successful dirigible balloon, as well as the many conflicting conditions that must be reconciled, have already been referred to in detail. How these are carried out in practice may best be made clear by a description of what may be considered as an advanced type of dirigible, the Clement-Bayard II, Fig. 12, of French design, and the most successful of the French military air fleet. In fact, the design of this airship incorporates all those features which the experience of aeronauts in other countries, notably Germany and Italy, has proved to be best adapted to aerial navigation, and it is said that future additions to the French aerial navy will be patterned after this type. Its predecessor, the Clement-Bayard I, Fig. 13, made thirty voyages, some of them of considerable distances, without suffering any damage, but a study of its shortcomings led to their elimination in the following model. The difference between the two may be realized by comparing the illustrations in connection with the following comments on the changes made and the reasons therefor.

The pisciform shape of the first Clement-Bayard has been retained, but it has been given more taper and more grace, the dimensions being 248.6 feet overall by 42.9 greatest diameter, this being but a short distance back of the bow. This gives it a ratio of length to diameter of 5.76. The gas balloonet stabilizers have been eliminated altogether, as will be apparent at first glance at Fig. 12. The total gas capacity is approximately 80,000 cubic feet. Like all French dirigibles it is of the true flexible type, the only rigid construction being that of the framework of the car itself. To the latter are attached all rudders and stabilizing devices, instead of making them a part of the envelope as formerly. The latter is made of continental rubber cloth.

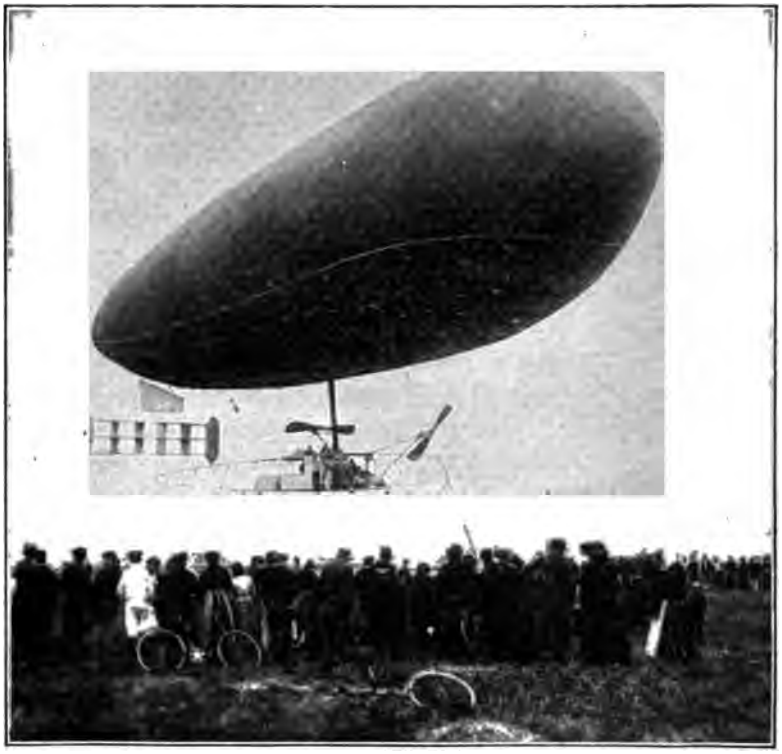


Fig. 12. Clement-Bayard II, French Dirigible

Light steel and aluminum tubing are employed in the construction of the frame supplemented by numerous piano-wire stays. This frame extends almost the entire length of the envelope, and carries at its rear end a cellular, or box-kite type of stabilizing rudder, instead of the former gas balloonets employed on the Clement-Bayard I, Fig. 13. This cellular rudder is in two parts, consisting of two units of four cells each, the two groups being joined at the top, with a space between them. In addition to acting as a stabilizer, this is also the direction rudder, its leverage being increased by making the end planes somewhat larger than the partitions of the cells. Between the cellular stabilizing rudder and the envelope is placed the horizontal rudder for ascending or descending. In the illustration this appears to be a flag, but it is in reality a long rectangular plane, which may be tilted on its longitudinal axis, the latter being at right angles to that of the balloon. There are two air balloonets of about one-third the total capacity of the balloon itself, and they are designed to be inflated by large aluminum centrifugal blowers driven from the main engines themselves.

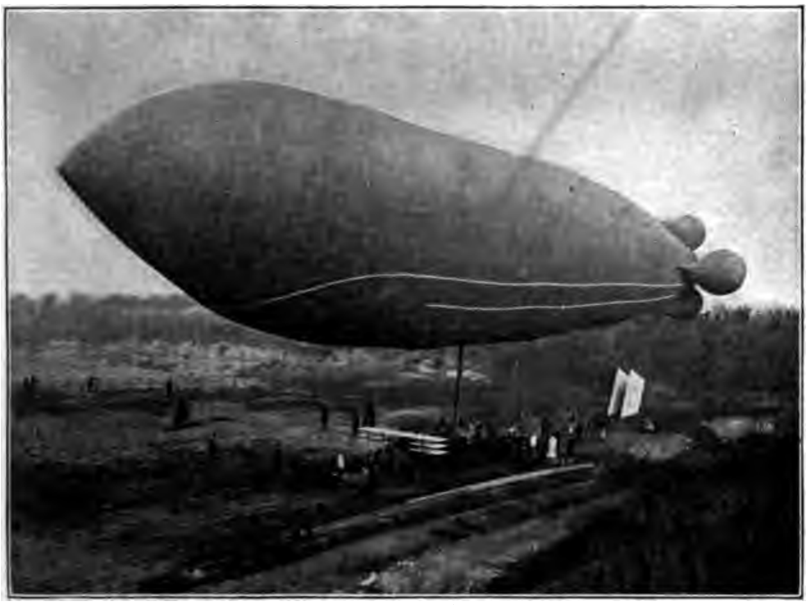


Fig. 13. Clement-Bayard I

There are two motors, each of 125 horse-power, both being of the same conventional design, *i.e.*, four cylinder, four cycle, vertical, water cooled. In fact, they are merely light automobile motors. The cylinders have separate copper water jackets and the motors themselves are muffled, which is a departure from the usual custom. Each drives a separate propeller carried on top of the main frame through bevel gearing.

The Clement-Bayard II made itself famous by its rapid and successful flight from the suburbs of Paris across the Channel to London, in October, 1910. This quick descent of one of the representatives of the French "fourth military arm" over the erstwhile sacred dividing line—the Channel—stirred the British mind, ever on the lookout for possibilities of foreign invasion, to an almost frenzied activity in aeronautical affairs. England at once entered the field and built one of the largest dirigibles ever constructed, "The Mayfly," a huge airship of the Zeppelin rigid type, which answered the query implied by its name, by not flying at all, as it was wrecked the first time an attempt was made to take it out of the shed, as mentioned farther along.

LATER FRENCH TYPES

Zodiac, Le Temps, Astratorres. After the disaster to La Republique in 1909, so little activity was shown in this field by France that the land which had given birth to the dirigible balloon seemed ready to discard what had been a source of considerable pride before it was equaled and then surpassed by Germany. From that time until the middle of 1911, only three very small units were added to the depleted French fleet, the Zodiac, Le Temps and Astratorres, and while these were very efficient for their size and were much used for training purposes, they made a sorry showing compared to what France had been doing previously. But while there was an apparent lack of interest in this branch, a general reorganization was actually being planned to build a new fleet of French military dirigibles capable of making altitudes of 6,000 to 7,000 feet, where they would be immune from any attack save that of aeroplanes which could be fought off. The scale on which this reorganization is planned is apparent in the amount of equipment used. To the only two airship sheds or "harbors" exceeding 400 feet in length previously to be found in the entire country, no less than nine have been added. All of these are 400 feet long and are so built as to be readily enlarged to 600 feet. Each of these is designed to accommodate two of the big dirigibles at once. There are no less than six large hydrogen generating plants in France, one of them having a capacity of 360,000 cubic feet per day, and others of similar size are to be added. The plans also include the building of a large fleet of big airships.

Lieutenant Selle de Beauchamp. The first squadron of the new fleet consists of four vessels, the Lieutenant Selle de Beauchamp, Capitaine Marechal, Adjutant Vincenot, and the Adjutant Reau, all of them having been named after the officers who perished in the La Republique disaster. Their type is a clever development of the old Lebaudy and the Ville de Paris, of the classic La France type, the Adjutant Reau and its sister ship being patterned after the Ville de Paris, while the other two are improved Lebaudys. With about 250,000 cubic feet displacement, a length of 270 feet, beam 38 feet and a power-plant consisting of two 80-horse-power motors on each, these are the smallest of the four, but the most interesting, as the Lebaudy type with its single short car does not lend itself so readily to enlargement from the engineering point of view.

The outlines are strictly of the Lebaudy type, but in the Lieutenant Selle de Beauchamp essential differences are to be seen in the suppression of the vertical stabilizing fin at the extreme stern, this being replaced by fixed surfaces forming part of the vertical rudders. All rudder surfaces are doubled, this feature making possible a saving of weight and representing standard practice on all large airships of recent construction. Part of the horizontal rudder planes are nearly amidships, where they act less as rudders than as true aeroplanes lifting or depressing the ship to an even keel. There are two large air balloonets, each of which is designed to be filled by a centrifugal blower of large capacity. These blowers are mounted directly below the balloon and each one of them is driven from a different motor through a vertical rope transmission. Either of these blowers may be employed to inflate either or both of the air balloonets, so that their duplication and coupling to different motors is a measure of precaution solely. The car is supported on a deep-trussed frame of steel tubing suspended some distance below the balloon, the propellers being mounted on tubular steel outriggers, while there is a perfect maze of suspension ropes and trussing guys in sharp contrast with the simplicity of the German dirigibles of either the rigid or semi-rigid types. This should not only prove a source of greatly increased head resistance, but likewise one of weakness and danger from which an airship designed for military purposes should be free. A year or two ago, the big Zeppelin rigid airships could not rise high enough to be considered a source of danger from a military point of view, but now that this type can ascend to a height of 6,500 feet and has an effective radius of action of over 600 miles, together with a nice regulation of ascent and descent, it appears that the German airships should be much more effective.

GERMAN DIRIGIBLES

Zeppelin Airships. At the same time that Santos-Dumont was carrying on his hazardous experiments, the problem was being attacked along slightly different lines by a retired German military officer, Graf von Zeppelin, or Count Zeppelin, as he is usually called.

When a mere boy he was constantly experimenting with air craft, and succeeded in making small flights, at one time falling 50 feet. He was indomitable in his purpose to invent a successful airship, and fought for his plans against the disbelief of all those around him.

It was not until he retired from the German army, that the Count gave up all his time to the construction of an airship. He received some aid from the German government, but most of the fortune put into his giant aerial craft was his own. In fact, he spent practically everything he had. Although he, like Santos-Dumont, employed a machine of the lighter-than-air type, the construction of the gas bag was radically different.

It will be remembered that Dumont experienced much trouble on account of the envelope of his balloon being too plastic, causing it to crumple in the middle and to become distorted in shape from the pressure of the air. His efforts to overcome this by employment of air bags did not meet with great success, even in his later types.

Construction. Zeppelin employed a very rigid construction. His first balloon, which was built in 1898, was the largest which had ever been made. It is illustrated in Fig. 14, which shows his first design slightly improved. It was about 40 feet in diameter and 420 feet long—an air craft as large as many an ocean vessel. The envelope consisted of two distinct bags, an outer and an inner one, with an air space between. The air space between the inner and outer envelopes acted as a heat insulator and prevented the gas within from being affected by rapid changes of temperature. The inner bag contained the gas, and the outer one served as a protective covering. In the construction of this outer bag lies the novelty of Zeppelin's design. A rigid framework of strongly-braced aluminum rings was provided and this was covered with linen and silk which had been specially treated to prevent leakage of gas. The inner envelope consisted of seventeen gas-tight compartments which could be filled or emptied separately. In the event of the puncture of one of them, the balloon would remain afloat. An aluminum keel was provided to further increase the rigidity. A sliding weight could be moved backward or forward along the keel and cause the nose of the airship to point upward or downward as desired. This would make the craft move upward or downward without throwing out ballast or losing gas. Under each end of the balloon a light aluminum car was rigidly fastened, and in each was a 16-horse-power Daimler gasoline engine. The two engines could be worked either independently of each other or together. Each engine drove a vertical and horizontal propeller. The propellers each had four aluminum blades. As will be seen from Fig. 14, the cars were too far apart for ordinary means of communication and so speaking tubes, electric bells, and an electric telegraph system were installed.

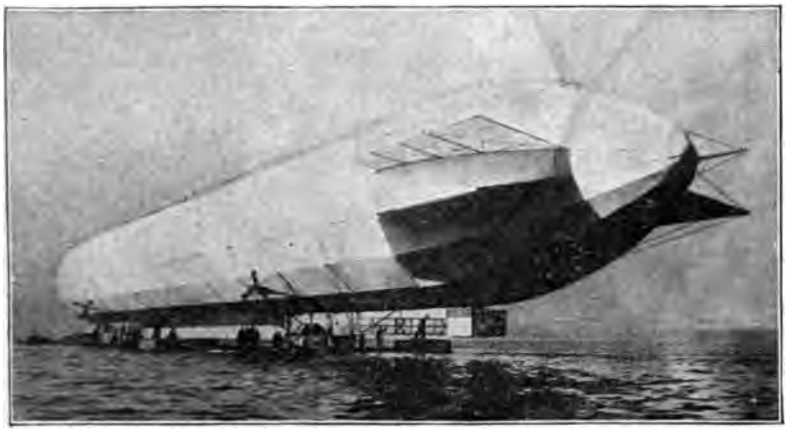


Fig. 14. Zeppelin Dirigible Rising from Lake Constance

First Trials. Very little was known as to the effects of alighting on the ground with such a rigid affair as this vessel, therefore the cars were made like boats so that the airship could alight and float on the water. The first trials were made over Lake Constance in July, 1900. The mammoth craft was housed in a huge floating shed, and the vessel emerged from it with the gas bag floating above and the two cars touching the water. She rose easily from the water, and then began a series of mishaps such as usually fall to the lot of experimenters. The upper cross stay proved too weak for the long body of the balloon, and bent upward about 10 inches during the flight. This prevented the propeller shafts from working properly. Then the winch which worked the sliding weight was broken and, finally, the steering ropes to the rudders became entangled. In spite of all this, a speed of 13 feet per second, or about 9 miles per hour, was obtained. These breakages made it necessary to descend to the lake for repairs and in alighting the framework was further damaged by running into a pile in the lake. The airship was repaired and another flight was made later in the year, during which a speed of 30 feet per second, or 20 miles per hour, was obtained.

Second Airship. Zeppelin had sunk his own private fortune and that of his supporters in his first venture, and it was not till five years later that he succeeded in raising enough money to construct a second airship. No radical changes in construction were made in the new model, but there were slight improvements made in all its details. The balloon was about 8 feet shorter than the original and the propellers were enlarged. Three vertical rudders were placed in front and three behind the balloon, and below the end of the craft horizontal rudders were installed to assist in steering upward or downward. The steering was taken care of from the front car.

The most important change was made possible by the improvement in gasoline engines during the preceding five years. Where, in the earlier model, he had two 16-horse-power engines, he now used an 85-horse-power engine in each car, with practically the same weight. In fact, the total weight of the vessel was only 9 tons, while his first airship weighed 10 tons.

His new craft made many successful flights. One was made at the rate of 38 miles per hour, and continued for seven hours, covering a total distance of 266 miles. During the course of the flight, Zeppelin made a landing to take on board a representative of the German ministry of war. In one trial flight with both motors in operation, the airship easily outdistanced the steamers on the lake. The German War Department finally took over the aeronaut's ship and plant, and the government appropriated $535,000 to help carry on the experiments. Since then Zeppelin has built several airships, all of the same type, and others are now under way of construction.

They embody no remarkable changes in design, the principal alteration being in size. The latter type is illustrated in Fig. 15. In one, the gas bag was increased to 446 feet in length and it held over 460,000 cubic feet of gas. This gave it a total lifting power of 16 tons. With this, Zeppelin made a voyage of over 375 miles. He was in the air for twenty hours on this trip and carried eleven passengers with him. In August, 1908, the Zeppelin left its great iron house at Friedrichshafen and sailed in a great circle over Lake Constance. This was to be the nucleus of the aerial navy and Germany considered herself the monarch of the air, as Great Britain was the monarch of the sea.

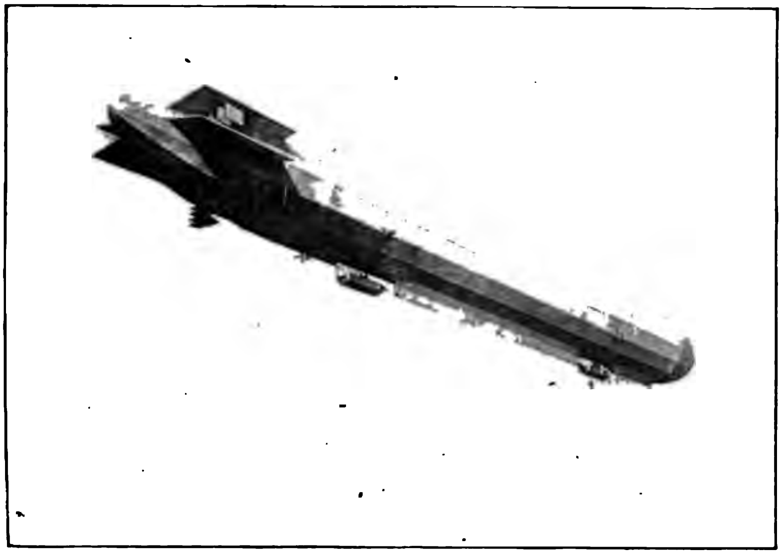


Fig. 15. A Zeppelin Airship in Flight

The next day, however, the ship was destroyed at Echterdingen in a storm. The German people at once came to Zeppelin's aid.

The government led a subscription list with $125,000. In all $500,000 was raised, and the Count again started work on a new aerial craft which was taken over by the government and christened Zeppelin I. On March 19, 1909, the Zeppelin I ascended with twenty-six passengers and maneuvered under perfect control for an hour and a half in a series of government tests.

Longest Airship Flight. Still another ship, the Zeppelin II, had been constructed, without the public knowing anything of its completion, inflation, or of the preliminary tests. It suddenly appeared before the world in a continuous flight of 900 miles. Count Zeppelin had not allowed a word to be made public relative to his intention of undertaking an endurance trip. It was, however, commonly believed that he intended to seize the first favorable opportunity to proceed to Berlin. On May 31, 1909, the Count in his newest aeronat descended at Göttingen at noon after a flight of thirty-six hours, during which he had covered 850 miles, thus more than doubling the best previous record in aviation for both time and distance.

The vessel had quietly left the floating shed on Lake Constance a little after nine o'clock at night, with Count Zeppelin himself, two engineers, and a crew of seven men on board. Starting from Friedrichshafen in a direct line towards Berlin, the great ship continued until it reached the frontier of Saxony, where it was headed straight for Leipsic. On it went, crossing Halle, into the very heart of Germany, as far as the great air harbor at Bitterfeld, where the Parseval airships were stationed in the large plant belonging to the Society for the Study of Motor Aeronautics. Lack of knowledge that such a thing as an air harbor existed in Bitterfeld led the press of the world to make the error that the ship had failed to reach her destination, which, it was assumed, must be Berlin, since the ship was headed in that direction. The airship after describing a great circle at Bitterfeld, turned again and sailed south.

Meantime the military authorities at Berlin were without advices as to the Count's plans, but they learned from private dispatches that the airship was approaching. An enormous crowd waited in vain for five hours in Berlin in the expectation of seeing Count Zeppelin arrive in his airship. The Kaiser came all the way from Potsdam, waiting on the moonlit field until ten o'clock, before word was received from Count Zeppelin that he had turned back.

The whole night long the flight toward Friedrichshafen was continued. In the morning it was found that a descent would have to be made to replenish the supply of gasoline. It was decided to cast anchor in a quiet valley which was protected by a steep hill just ahead of them. In the descent, the airship's bow prevented the man at the helm from seeing straight ahead, and, while the craft was closely skimming this hill, a pear tree suddenly shot up in its course. For the first time there happened in the air what so often happens on the water—the ship was steered right into the obstacle. From the ground it seemed for a moment as though the craft were doomed to certain destruction, as it appeared to be swooping straight into the trunk. When the big ship hung for a second and then forced its way through and circled slowly around a cheer went up from the relieved watchers underneath. It was found that the bow was crushed and the forward frame torn away.

In preparing for the trip to Friedrichshafen from the scene of the accident, all the damaged portion was cut away in front of the forward car, and the motor and propellers removed. The pointed bow of the ship was thus changed to a flat disk shape, but was so covered with cloth as to give a slight suggestion of pointed shape. A man was stationed in the passageway between the cars to act as a moving weight, thus assisting the rear planes to maintain the balance, as the forward planes had been destroyed. The speed was necessarily slow, and owing to the greatly diminished carrying power, the ship stopped for fuel while under way. Friedrichshafen ultimately was reached in safety.

The airship in which Count Zeppelin accomplished this flight was 448 feet long and had a diameter of 42 feet. It was equipped with two motors which furnished 220 horse-power. Besides being the largest dirigible in the world, its claim for carrying capacity is as yet uncontested.

On June 29, 1909, Zeppelin I, under command of Major Sperling, started from Friedrichshafen to go to its future home port at Metz. A breakdown in the engine room enforced a landing on the plains not far from Lake Constance. While the ship was waiting for duplicate parts of machinery a heavy gale arose, which prevented the continuation of the voyage even after repairs were completed. For nearly a week the storm-bound vessel was exposed to the violence of the elements, under the open sky, without damage to the craft. Flight was resumed on the night of July 3, and Metz was safely reached on the morning of July 4. The Zeppelin III, larger and more powerful than its predecessors, was then being built. On August 27, it made a successful flight from Friedrichshafen to Berlin.

Deutschland I and II. In honor of the governmental assistance that made their building possible, the later Zeppelin aircraft were named in honor of the Fatherland. The first of these was the largest airship that had been built up to that time (1910), but like her predecessors she was found to be more or less cranky, to apply a marine term by analogy. In other words the maneuvering ability of the craft was defective. Also like her predecessors, her existence was an extremely short one. Due to the motors failing at a critical moment, which coincided with a lack of buoyancy, the airship could not be kept afloat and as luck would have it, this occurred over a pine forest into which the huge hulk sank, the envelope being impaled at numerous points on the tops of the trees and the car and fittings being badly wrecked.

To provide greater lifting power for just such emergencies, the hull of the Deutschland II was made lighter, permitting the transportation of a greater amount of ballast for the same number of passengers. In other respects, the new airship was scarcely more than a copy of her predecessor and with no greater speed or any better maneuvering qualities. To further provide against accidents of a similar nature, special tests were made over Lake Constance to familiarize the crew with the exact amount of lifting and depressing power obtainable from the propellers and rudders alone. It was found that with only two motors and two propellers in action, the new ship could be raised by power like an aeroplane, from a static level of equilibrium at an elevation of 2,132 feet to 4,756 feet. This represents a purely dynamic lift of more than two tons (4,400 pounds). With three motors and four propellers the ship rose to 5,904 feet, adding nearly another ton of dynamic lift (1,980 pounds). It remained for some time at this level, carrying four passengers, the regular crew of nine, 242 pounds of fuel and oil, and 4,400 pounds of ballast. If one-half of this ballast had been thrown overboard, an elevation of 7,544 feet could have been reached, while still retaining more than a ton of ballast in reserve. This shows an astonishing reserve of floating power for the arrow-like type of Zeppelin balloons under favorable conditions, *i.e.*, with the motors intact and when not overloaded with passengers, and it would add greatly to their value for military purposes. At such heights they would be immune from artillery fire. Despite their huge bulk, their diameter does not exceed the spread of wing of a Wright biplane, which at the same height is an almost invisible speck, while a Zeppelin at the same altitude looks like a match, its lean shape making it a poor target. In the thin air, its speed is increased, so that with a favoring wind, even the slow Deutschland could make 60 miles an hour.

Although the new Deutschland was thus amply insured against conditions such as caused the wreck of its predecessor, it shortly fell a victim to an odd and unforeseen accident—collision with the shed. It hardly seems proper to term such a mishap either odd or unforeseen when it is recalled that a majority of the huge airships of recent build have all come to grief in a somewhat similar manner, *i.e.*, in being taken out of or returned to the shed, the breaking in half of the biggest of them all, the British naval dirigible, being a noteworthy case in point. As in the case of the latter, the Deutschland also "broke in two." Mishaps from apparently trivial causes, resulting from lack of experience in handling such huge craft, involve great losses of money and prestige when they happen to a large and costly dirigible, whereas they are almost negligible in the case of the aeroplane.

Schwaben. Taking advantage of the experience gained in the building of the two Deutschlands, Zeppelin set about building another and this—the Schwaben—was almost half completed at the time the second Deutschland was wrecked. The new airship was specially designed for passenger carrying and its dimensions marked a decrease in the huge proportions that characterized its predecessors. The dimensions of the last Deutschland were 499 feet length overall, diameter 46 feet, and with 18 independent gas compartments, giving a displacement of 667,560 cubic feet; whereas the displacement of the Schwaben is 634,500 cubic feet, on a length of 462 feet, the beam being 46 feet. The envelope is divided into only 17 gas compartments or cells. Numerous experiments were made to improve the shape of the hull, as the result of which the conical bow of the Deutschland was replaced by an ovoid shape in the Schwaben. To diminish friction the outer envelope of the new ship was stretched over the frame with extreme care so that it is so smooth and firm that non-technical observers have compared the "solid hull" of the Schwaben (swallow) to a man-of-war, owing to the gray color. To further cut down head resistance, the time-honored aeroplane rudders, fore and aft, were abandoned—quite a radical step as they had always proved efficient. In their place, a single set was attached to a more graceful single rudder frame at the extreme rear, where they are combined with vertical rudders and cleverly supported by stabilizing fins. It was found that by this means, skin friction and head resistance were cut down, steadiness improved and the efficiency of all the rudders wonderfully increased, so that the big ship could make a complete turn in a circle of only 800 feet radius. What was even more surprising was the fact that the lifting power did not suffer by the removal of these lifting planes, the kite effect of the smooth cylindrical hull compensating for their absence to an extent that substantially increased the floating power of the Schwaben as compared with Deutschland II, owing to the greater speed of the former. The lack of efficiency of an aeroplane surface with a very small aspect ratio, or very long in its line of longitudinal movement, as must be the case when attached to a big envelope, is offset in a dirigible by the small weight it has to bear dynamically per square foot of its immense area. As the result of long-continued experiments in the Zeppelin laboratory, the Schwaben was fitted with two- and four-bladed propellers of greatly increased efficiency, while the head resistance of their supporting brackets was greatly reduced by covering them with cloth in the form of useful stabilizing fins. The result of these improvements was apparent in the greatly increased speed, the Schwaben making a fraction under 43 miles per hour in calm air in the course of numerous trial trips carried out over a measured stretch of railway line, in both directions. As this rate of travel is equal to that of many of the large biplanes which have only an effective speed of 40 miles per hour, it revolutionizes all former ideas regarding the inferiority of the dirigible in this respect as compared with the aeroplane. With only three of the four motors running, all previous dirigible records were broken by making 38 miles per hour. In a race from Darmstadt to Frankfort, the Schwaben proved an easy victor over a

Euler biplane. This great improvement in speed has been due not alone to a decrease in the head resistance, but likewise to the increased efficiency of the motors, as after long experimenting with automobile types, Zeppelin abandoned them and built special engines in his own plant for the Schwaben. Six-cylinder motors are employed instead of the fours previously employed, and their output increased from 110 to 165 horse-power, so that the total driving power of the new ship is 660 horse-power. Their reliability was also greatly improved, so that in over a hundred passenger trips, of which some were 700 miles long, the Schwaben's engines have never given any trouble. The success of the numerous passenger trips was not only due to the increased power but also to the perfected methods adopted of handling the big ship at landings. Mechanical docking devices have been provided by which the ship is securely held until safe in the open air, before an attempt is made to take it into the shed. A rail on each side of the shed runs far out into the open through each of the doors at both ends. Each length of rail is made of two narrow channel plates riveted together back to back. Two sets of rollers run on each rail, each set bearing against the under side of the upper flanges. Four steel cables made fast to the airship's frame are attached to the four sets of rollers, or trolleys, and all may be slipped simultaneously. The two rails are so far apart that a dirigible lashed to them can not be swayed if it have sufficient lift, this being obtained by the removal of the passengers and ballast before pushing the ship into the shed, and not taking them aboard again until the big craft is safely out of the latter again before starting a flight, which begins by the simultaneous release of all the hawsers. But entering the shed with a brisk wind blowing at right angles to its axis and to the rails is still a difficult feat. In this case, the ship is halted in the open over the track, heading into the wind. One of the front cables is fastened to the rollers nearer the shed on the windward rail. With this set of rollers as a fulcrum, the ship is worked around by pulling at the rear end, steadying it along the sides, and simultaneously pulling the lee side down, until it becomes parallel with the rails. It is then a simple matter to fasten the remaining cables, unship passengers and ballast, and roll the craft into its house. Even with these improvements, the device is still primitive and depends upon the employment of a large number of men skilled in handling the big aircraft. Damage from accidents of this nature has also been further provided against by strengthening the structure of the ship itself, the cars and cabin being built of corrugated aluminum, while the strength of the pneumatic buffers under them has also been increased. Of equal importance to the improved methods of docking are the provisions for safely anchoring the huge dirigible in the open. A safe anchorage over unobstructed grounds, mostly parade grounds, has now been provided in most German cities.

The holding device is a development of the method by which in the past severe squalls have occasionally been weathered. It differs from the latter in that the pivotal point around which the ship swings into the wind's direction is now placed on the frame of the ship itself, instead of on the ground. Even with the short single bow cable formerly used successfully, jerks which strained the frame and the cable were not entirely avoided in gusty winds, too much play in the bow having snapped the long cable and freed the ship on one occasion, though it did not damage the frame. In place of the single cable there are now four, giving greater safety. They are fastened to a ring that swivels round a strong pin in the reinforced framework and are permanently carried by the ship. When anchoring, their free ends are made fast to four heavy cubes of concrete embedded in the ground, and so placed that the four cables evenly radiate toward them from the pivot on the bow. Due to its rigidity, the ship turns freely around the apex of this pyramid of cables as smoothly as a new weather vane. Unshipping ballast at the bow makes this pyramid very rigid.

Plans have been completed for the inauguration of an American dirigible passenger service similar to that in operation between the cities of Berlin and Frankfort during the past two years. Airships similar to the Schwaben will be employed, the route being between Philadelphia, Atlantic City, and New York, the stopping place in the first-named city, which will be the headquarters, being erected on the roof of the Bellevue-Stratford hotel. This landing platform will be 190 feet long by 62 feet wide and at an elevation of 300 feet above the ground. It is to be finished with a surface of sod and clay similar to a baseball diamond. One round trip per day will be made, the fare being the same as in Germany, that is, $50.

Parseval. Germany has adopted another type of airship, that of Major von Parseval. His construction is very different from that of his compatriot, Zeppelin. Instead of the rigid construction of the latter, the Parseval has no rigid connections except between the car and the propeller. Two air balloonets are employed, one inside each end of the balloon, the pumps being so arranged that either one can be filled or emptied independent of the other, allowing the balloon to tilt upward or downward as desired by the pilot. In addition, the car itself is on two rollers and can be moved forward or backward on two cables, thus placing the weight so as to cause the balloon to tilt. The surfaces which steer the balloon are blown under pressure. The propeller has four blades, and is driven by a 90-horse-power gasoline engine.

The Parseval's peculiarity lies in its propeller. Instead of the solid blades common to other airships, there are four strips of canvas with weights at the end, held rigid by centrifugal force when in motion, and hanging limp when the ship is at rest.

The Parseval II was of almost the same construction, and had a promising though short career. It collapsed ignominiously on the roof of a villa after a flight of over eleven hours. A new Parseval II has been constructed, and stationed at the new government air harbor at Bitterfeld. It has two motors with a total horse-power of 240.

Parseval Sporting Type. The Parseval flexible system having proven such a success, the makers (Die Motor-Luftschiff-Studiengesellschaft, Berlin) have brought out the Parseval V. The original intention was to design a dirigible of the smallest dimensions compatible with the system, and while, according to theory, it would have been possible to reduce the dimensions considerably more than has been the case, the miniature thus obtained would have been a mere toy, devoid of any practical value. The new Parseval, accordingly, has been built to carry three persons and a sufficient amount of ballast for a six- to seven-hour run at a speed of not less than 20 miles per hour. The Parseval V thus constitutes the smallest of its class and is mainly intended for the use of private parties and aeronautic clubs. Its dimensions are 129 feet overall, maximum diameter 25.3 feet, and its displacement 42,000 cubic feet. The envelope is made of lined balloon fabric of a minimum strength of 730 pounds

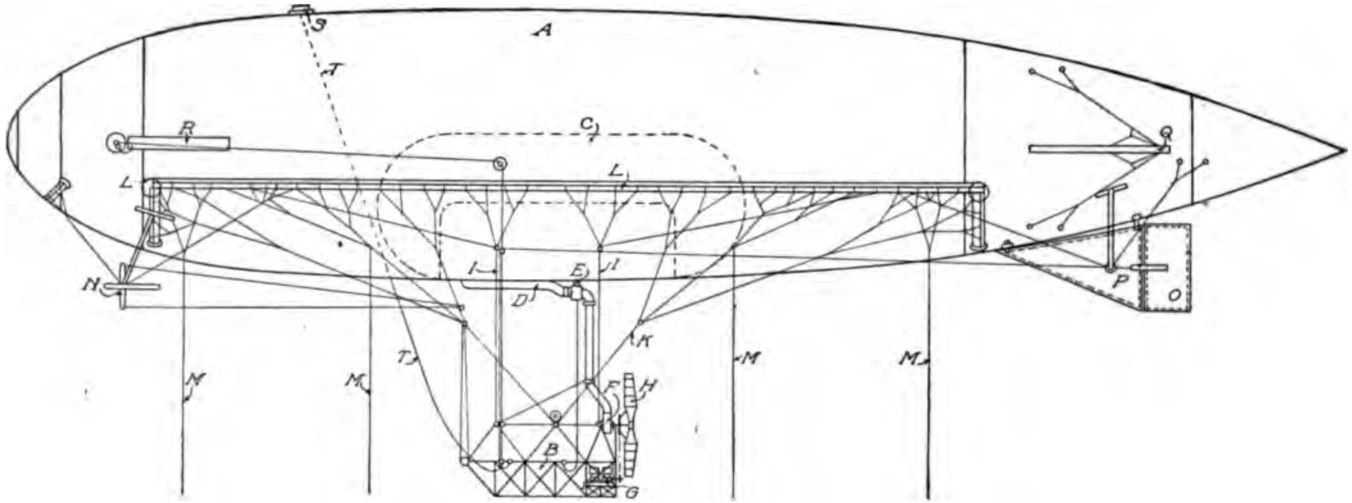


Fig. 16. The Parseval V

A, Balloon body; *B*, Car; *C*, Ballonet; *D*, Conduit connecting ballonet to air pump; *E*, Ballonet valve; *F*, Air pump; *G*, Motor; *H*, Propeller; *I*, Parallelogram ropes; *K*, Sliding ropes; *L*, Belt; *M*, Lifting rope; *N*, Elevation rudder; *O*, Side rudder; *P*, Vertical stabilizing surface; *Q*, Horizontal stabilising surface; *R*, Emergency valve for rapid discharge; *S*, Gas valve; *T*, Valve rope.

per foot, and weighing one ounce per square foot. The balloon is made up of a number of longitudinal sections, a construction which somewhat reduces the fractional resistance of the surface. The details of the construction are illustrated in Fig. 16. It shows the characteristic Parseval shape, rounded off elliptically in front and tapering to a slender point in the rear, in other words, the housiform outline recommended by Renard. A distinctive feature wherein it differs from all others of the same make is that the vertical steering is effected by a horizontal rudder located at the head of the balloon and operated by cables from the car, instead of the usual balloonets. This has worked so well in practice that the little airship is capable of maneuvering within a few yards of the ground without danger. A single centrally-placed air balloonet fed by a centrifugal air pump is provided to take care of expansion and contraction, as well as gas losses. To prevent excessive stress being placed on the envelope a safety valve is provided in the flexible pipe connecting the pump and the air balloonet. This valve opens automatically when subjected to a pressure equivalent to 0.6 inch of water, allowing sufficient air to escape from the balloonet to maintain the normal pressure.

The gas valve which is located at the summit of the balloon is also designed to operate as a safety valve, but as it does not operate of its own accord until a pressure in excess of one inch of water is reached, no gas losses occur unless the expansion of the gas has forced all the air out of the balloonet. Both of these valves may also be operated by cables leading to the control board. The usual "ripping valve" is also provided in the form of a narrow strip of balloon fabric glued over a long cut in the envelope. This can be ripped open in cases of emergency at a moment's notice. The stabilizing surfaces are of triangular outline and are combined with the direction rudder at the rear. They consist of frames of steel tubing autogenously welded together and tautly covered with light balloon fabric, provided on both sides with vent holes into which air is forced by the movement of the airship when in flight, thus keeping the fabric tight and smooth. Side and front elevations of the car are shown in Figs. 17 and 18. It is built of steel tubing and measures 14.75 feet in length by 3.25 feet high, being 2.79 and 2.13 feet wide at the top and bottom, respectively. Though the normal carrying capacity is three, including the pilot, there is sufficient accommodation for four, but as all the controls are centered at the pilot's stand forward, the airship can readily be handled by one man. The power plant is compactly arranged at the rear of the car. The engine is a four-cylinder, 25-horse-power Daimler motor, running at 1,200 r. p. m. and using but 0.54 pint of gasoline per horse-power at full load. The flywheel acts both as a fan and a belt pulley for driving the pumps, and the radiator is placed directly behind it, the main driving shaft passing through the radiator and being supported by an outboard bearing back of it. The propeller is placed upon a bracket above the motor and is driven by a silent chain, the two sprockets having a ratio of 4 to 1. The propeller is of the 3-bladed type with a diameter of 9 feet 9 inches and differs from those of the earlier Parseval airships in that the blades are semi-rigid, being constructed on a framework so pivoted at the base of the blade as to prevent the stresses upon the latter reaching a point dangerous to their safety. The suspension of the car

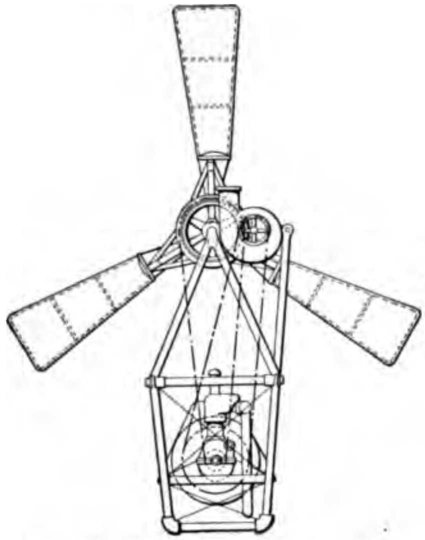


Fig. 17. Front Elevation of Parseval V

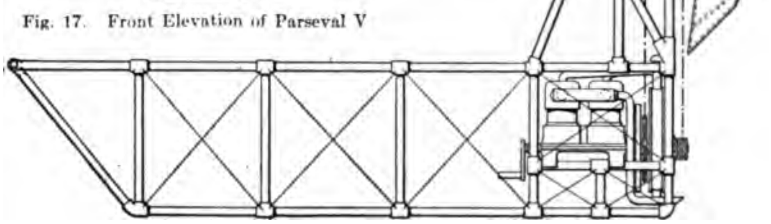


Fig. 18. Side Elevation of Parseval V Showing Motor and Transmission Gear

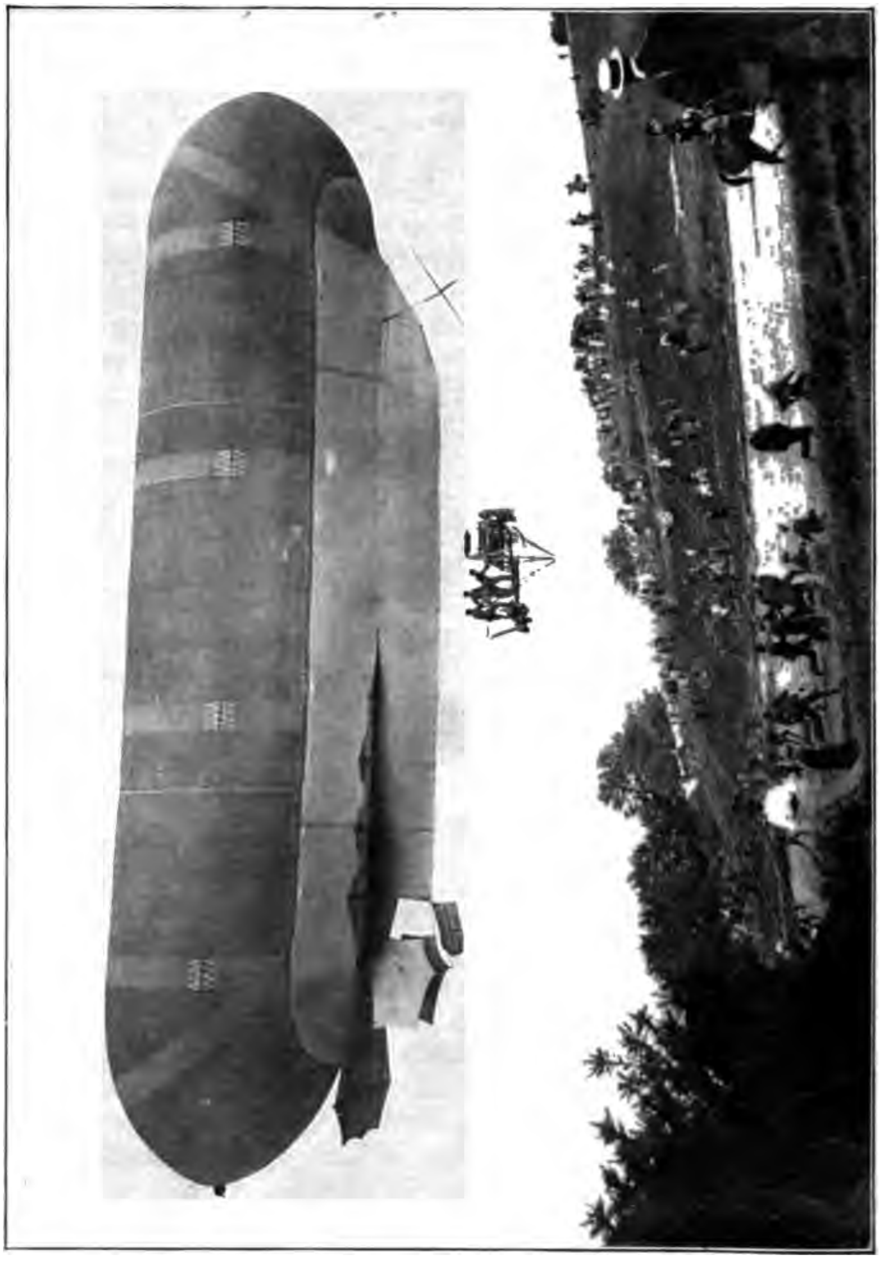
is analogous to that of the larger Parseval types, except where slight alterations were necessary owing to the reduced dimensions, the car depending from the balloon by cables arranged in parallelogram form so as to always keep it hanging in a direction parallel to the longitudinal axis of the balloon. But it is otherwise free to travel back and forth in a path controlled by two idlers on sliding ropes running obliquely fore and aft. This arrangement prevents any accidental inclination of the balloon in starting due to the thrust of the propeller, which accordingly always acts with its driving point located at the center of resistance of the airship.

Gross. The Gross has also been approved by the German government. This is a dirigible of the usual type driven by two 75-horse-power motors.

The Gross II has been recently built for the Prussian Aeronautical Battalion under the supervision of its commander, Major Gross. It is almost identical with the Gross I. Its movements are kept more or less secret, but it frequently crosses over Berlin. Two hangars or air harbors have been constructed for the Gross I and her sister ship.

Krell I. That it is possible to build a successful airship of the imposing dimensions of the various Zeppelin craft without the characteristic rigid frame deemed indispensable by the latter, is shown by the test of the Krell I, which was finally launched in the fall of 1911, after two years had been spent in its construction. All the weight saved by the elimination of the rigid frame has been put into additional propelling power, and as the new airship has almost as low a head resistance due to its rigging as the Zeppelin, and a total of 500 horse-power, as compared with the 165 horse-power of the first of the latter type, its speed is much greater. The Krell I may best be described as a "non-rigid Zeppelin." Its large size—393.7 feet long by 42.65 feet diameter with a displacement of 473,739 cubic feet—makes necessary a slender-shaped balloon, similar to that of the Lebaudy non-rigid dirigible, the Morning Post, previously described, because even the natural static pressure of the gas against the back of the envelope when under way, due to the greater "head" of gas resulting from increased beam, acts as a stiffener. This clearly illustrates how much of its strength the big Zeppelin derives from the pressure of the gas alone, quite independent of the rigidity of its frame. There is the same long passageway of triangular cross section running the entire length of the ship directly below the balloon, but in this case, it is made of cloth without any stanchions, the only rigid part of it being the flooring, though it is said to feel no less solid than the Zeppelin construction. This not only provides communication between the three cars, but also houses the water ballast tanks as well as the fuel and oil tanks, thus distributing the load over the entire length. The three cars differ from those used on the Deutschland in that the pilot's bridge has been placed in the center car, instead of the forward one, thus permitting two motors to be placed in the latter and the other two motors in the after car. The passengers are carried in the center car. However, the propellers being directly mounted on the cars and not on the flexible hull, thus avoiding long transmissions, more propellers have been provided. There are three on each car, or six in all. In each of the forward and after cars, a 125-horse-power motor drives two 2-bladed propellers, mounted on outriggers at the sides, while the other motor of the same power drives a single 4-bladed propeller mounted directly on the elongated shaft of the motor extending behind each car. These shafts are supported by steel tubing in pyramid form. The two engine cars are so far apart that no interference results from this compact arrangement, especially as the center is raised to the same level as the other two, following Zeppelin practice in this respect. The auxiliary power plant is carried in the center car, and as the blowers for maintaining the necessary pressure in the air balloonets must naturally be large on an airship of such size, this takes the form of two 25-horse-power motors. Only one is employed, the other being held in reserve. The three cars are only slightly lower beneath the hull than were those of the Deutschland, the short suspension cables being made fast to the cloth sides of the long passageway. But several auxiliary cables are also led from the cars directly to the envelope to which they are attached, as in the Parseval type, by layers of bands or huge reinforcing "patches" sewed to the outside of the balloon. Horizontal rudders, similar to those of the Zeppelin, are employed, but they are much smaller and are mounted on the sides of the passageway instead of directly on the balloon. They are placed above the front and rear cars and there is also a horizontal propeller, placed beneath the floor of the center car, designed to be driven by the reserve motor in case of emergency. Communication between the cars and the passageway is by means of ladders, the cars themselves being surrounded by a tubular framework resembling a cage. The huge vertical rudder is similar to that of the Clement-Bayard II. It is like a Venetian blind with five slats and is mounted just below the easy curving stern, being supported by a tubular framework secured to the envelope at points protected by reinforcing patches, in exactly the same manner as the Parseval construction of this essential. The shape of the hull is also similar to that of the Parseval, but it has been elongated to such an extent as to more closely resemble the Zeppelin.

Veeh I. In contrast with all of the German dirigibles thus far described, the Veeh embodies many of their features, but at the same time differs radically from every one of them. It is of the semi-rigid type, but is of such novel construction as not to resemble any of the airships of this type previously built. The frame is in the form of a single girder extending the entire length of the balloon, from the tip of the bow to the point of the stern. It is in the form of a keel and is built up of light steel tubing. This results in quite a novel form of airship. As the balloon is rigidly connected with the steel keel throughout its length, all forces are well distributed and the necessity of compensating for any stresses by an excessive tension of gas pressure is eliminated. The envelope is thus subjected to considerably less strain and the risk of explosion greatly reduced. The rigid girder frame also permits of a simple and compact arrangement of the power plant and drive besides affording a solid support for the stabilizing surfaces and the rudder. Two pairs of 2-bladed wood propellers, 13.2 feet in diameter, are driven by two six-cylinder, 150-horse-power motors through triple, parallel, rubber cables. The propellers are enclosed in light metal cases to protect the envelope and the passengers in case the propeller should break under the high centrifugal stresses. The lateral rudders are placed in the air current developed by the propellers, which makes them so effective that the airship may be turned practically on its own axis. Both the elevating rudders and the stabilizing surfaces are solidly supported by brackets attached to the steel keel, the tubular framework of the latter being covered with fabric and in



part closed up by panels of cloth, to cut down the head resistance. These panels also act as lateral stabilizing surfaces in addition to affording shelter for the passengers. The envelope is of metallized balloon fabric with a capacity of approximately 9,800 cubic yards and in the form of an elongated cylinder with comparatively blunt ends of similar shape. It is subdivided into nine independently dismountable gas compartments and is provided with two air balloonets, each of about 1,100 cubic yards capacity. The airship measures 248 feet in length and has a spacious trapezoidal gondola between the frame of the keel, measuring 132 feet long by 3.3 feet wide at the center. Inclusive of the frame, rudder, stabilizing surfaces, propellers, motors and drive, the total weight is only 3,100 pounds. With a fuel supply sufficient for a 10-hour flight and the full complement aboard, the airship still has a reserve buoyancy of 2,200 pounds. Skids and spring-mounted wheels are provided below the frame to absorb the shocks of landing. Owing to the remarkable simplicity of the design and the low cost of the materials employed, the expense for construction is comparatively small.

BRITISH DIRIGIBLES

In spite of the fact that a great deal of money has been spent upon the building of dirigibles in Great Britain during 1910 and 1911, the results have amounted to little or nothing, being confined practically to the short trips of the Nulli Secundus and the various trials and tribulations that the Morning Post has suffered almost every time an attempt has been made to fly her. The last-named airship is a large Lebaudy type constructed in France, while the former is of British design and construction, having been built for military purposes. As dirigible standards go nowadays, however, the Nulli Secundus is only a third- or fourth-rater. Fig. 19 shows the general construction excellently. It will be noted that the direction rudders are placed forward instead of at the stern, as is the usual practice. The gas bag is provided with a hull or keel, similar in form to that of a ship, and from this is suspended the car. At the forward end and on either side of the keel is a series of five horizontal projecting fins, by means of which the airship's course can be deflected up or down. At the stern and on a level with the bottom of the keel, is a transverse horizontal plane which forms an additional rudder for use in ascending and descending. The Nulli Secundus has a length of 111 feet and a capacity of 85,000 cubic feet. She is driven by two propellers run by a single motor and is capable of carrying three persons at a speed of 20 miles per hour. Instead of employing the usual balloon cloth of cotton or silk combined with rubber, the gas bag is made of eight layers of goldbeaters' skin—about as expensive a material as could well be found for the purpose. This is made from the lining of the digestive tract of cattle and about 60,000 animals were necessary to furnish sufficient for the making of this one envelope. Compared with the one insignificant dirigible of 30,000-cubic-foot capacity owned by the United States, the Nulli Secundus takes on considerable importance, but when judged according to the standards set by the Continental governments, she is a negligible factor. Two or three of this type have been built for British military use and are employed in training army officers.

A huge British dirigible for naval use, and of which much was expected, was built during the winter of 1910—1911. In its dimensions as well as in its numerous special features of design and arrangement, this monster was to surpass anything of the kind that had ever been built, and its ability in the air was to be in proportion. Unlike previous British dirigibles, the Mayfly, as the big ship was named, was built with a rigid frame similar to the Zeppelin type. There probably have been few airships built in any country that involved the expenditure of so much money as this one, but the only reward of months of labor and waiting was to see her ignominiously broken in half when an attempt was made to take her out of the shed.

AMERICAN DIRIGIBLES

United States War Balloon. At The Hague Peace Congress, the representatives of the United States signed a clause by which she, of all the first or second rate powers, was debarred from using airships as a means of offensive warfare. Yet the United States, by the purchase of the Baldwin dirigible balloon in 1908, committed herself to a policy of maintaining airships as a part of her military equipment.

The Baldwin was the only one of the three aerial craft that fulfilled the government requirements during the trials made that summer at Fort Meyer, Virginia. Specifications were sent out by the chief signal officer of the army, inviting bids for a dirigible balloon. Among the proposals received was that of Capt. Thomas Baldwin, and after the official trials the contract was awarded to him. He delivered his airship in August, 1908, and it received the name, Dirigible I. It has a length of 96 feet, a maximum diameter of 19½ feet, a volume of 20,000 cubic feet, and is designed to carry two persons. At its official trial, it made a maximum speed of nearly 20 miles an hour, and remained in the air for two hours, covering a distance of 27 miles. A general view of the United States army airship, Dirigible I, is shown in Fig. 20.

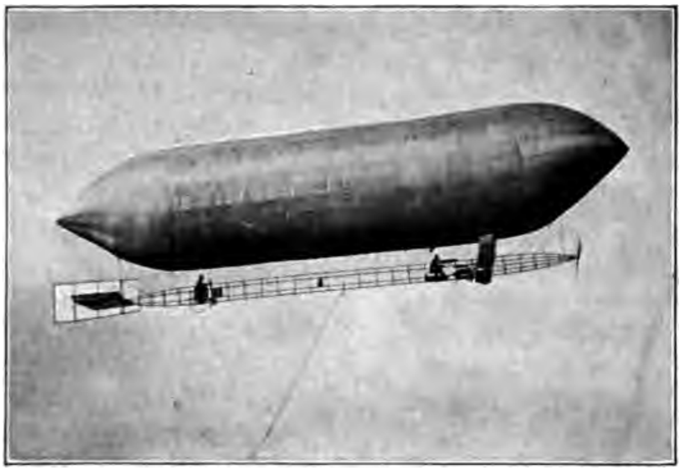


Fig. 20. Captain Baldwin's Dirigible, the United States Army Dirigible I

The America.* As Wellman's attempt to cross a stretch of 3,000 miles of ocean in a dirigible was by far the most ambitious undertaking of the kind ever attempted, a detailed description of the airship and the numerous special features designed to make such a lengthy voyage possible will be of interest. Contrary to the general impression, this was not the same dirigible in which the unsuccessful attempt to reach the North Pole from Spitzbergen was made.

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*Excerpt from Chief Engineer Vaniman's detailed description of the America.

The balloon itself measured 228 feet in length overall, and had a diameter through its greatest transverse section of 52 feet, giving it a lifting power of close to 12 tons, or to be exact, 23,650 pounds. The weight of the envelope alone exceeded 2 tons, the balloon proper being made of a costly fabric composed of two layers of silk and one layer of fine cotton cloth, gummed together with rubber. There were about 4,000 square yards of this rubberized cloth required, weighing approximately a pound to the yard, and having a tensile strength of 100 pounds to the square inch. This combination was adopted as the silk and cotton provide great strength to resist the internal and external pressure, while the rubber binder made the fabric almost gas-tight.

At the center of pressure, or the greatest diameter of the balloon, the fabric was used three-ply, and the most painstaking care was used in every detail of its construction to obtain the maximum strength and at the same time reduce the gas leakage to a minimum. The seams were wide lapped, sewed, and gummed, and extra strips were glued over them to cover the needle holes to prevent the escape of the gas. As the weight of the balloon complete with its air balloonets, valves, and other appurtenances was 4,700 pounds, it had a net lifting force of 18,950 pounds. In other words, the volume of gas required to inflate it was sufficient to carry its own weight in the air and a load of almost 9½ tons besides. Although hydrogen gas has a weight of only one-fourteenth that of air, it required more than a ton of it to inflate this huge gas bag to its full capacity. The manufacture of this quantity of gas was not an easy or inexpensive operation. The plant to generate the gas was made in Paris, shipped to Atlantic City in sections, and there set up just outside of the shed housing the airship. More than 100 tons of sulphuric acid, 60 tons of iron turnings, and hundreds of tons of water were needed for the process. Before being admitted to the balloon the gas had to be thoroughly cleansed and purified to make it as light as possible and eliminate all acids that might destroy the costly fabric of the balloon. This was accomplished by "washing" the gas, or passing it through water, and subsequently drying it by again passing it through cylinders filled with coke, permanganate of potash, and calcium of lime. As pure hydrogen is odorless and gives no sign of its presence when escaping, several gallons of oil of peppermint were used to perfume it in order to immediately detect leaks. The cost of inflating the America exceeded $5,000.

Type of Construction. The type of construction employed was what is known as the "semi-rigid" similar to the Gross (German) dirigible, *i.e.*, a rigid suspension depending from a flexible gas container. The car measured 156 feet in length and consisted of a truss of triangular section, built up of light steel tubing shown in Fig. 21, and more in detail in Fig. 22. The bottom chord of this truss was a cylindrical steel tank with pointed ends, 75 feet long, employed for carrying the main supply of gasoline, and having a capacity of 1,500 gallons. At the top of the truss a series of transverse brackets was placed, the bag being attached to the car by means of rope connections between the ends of these brackets and a strong band, or web, formed on the envelope itself. This *relingue*, as the French

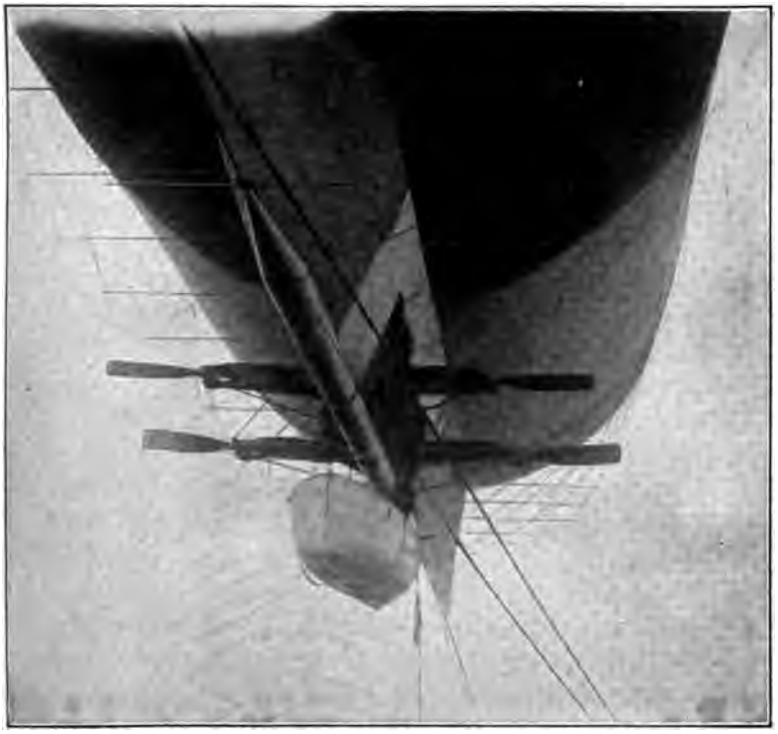

Fig. 21. Wellman's Airship "America," Showing Arrangement of Car

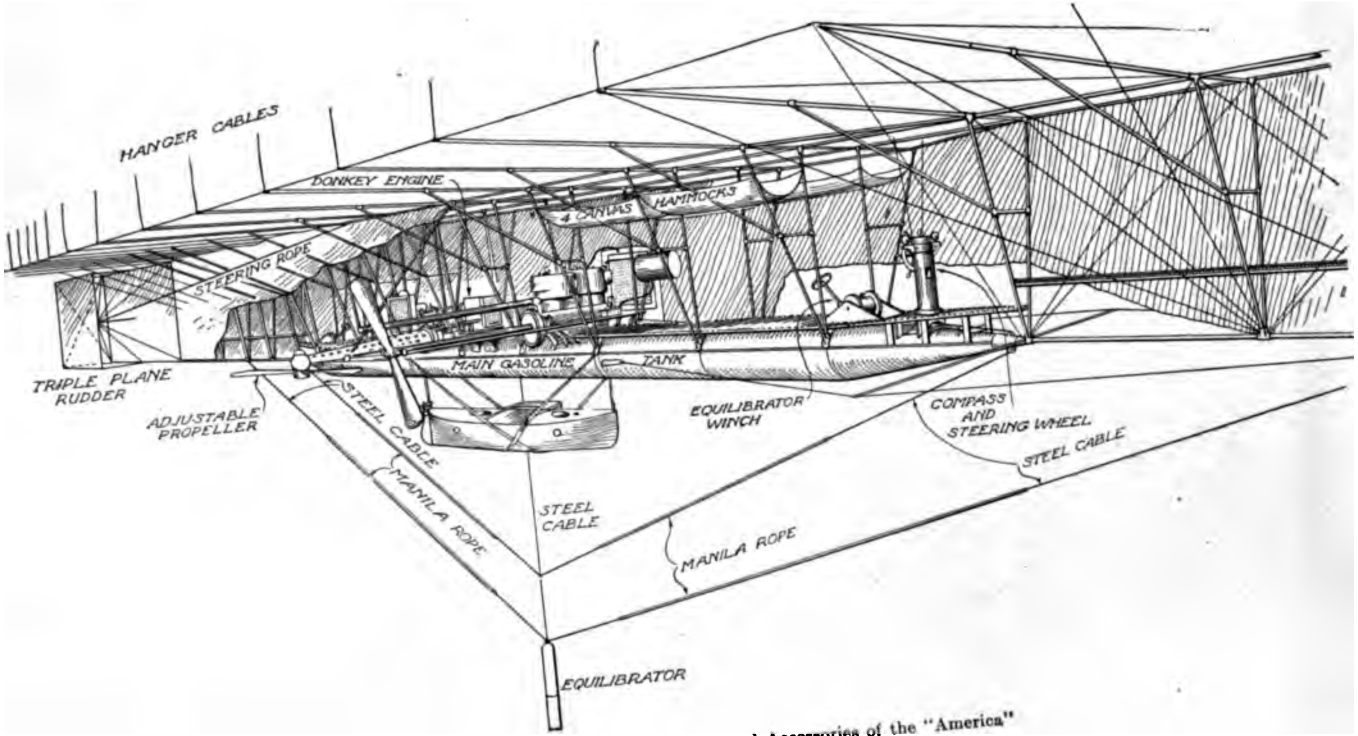

Fig. 22. Structural Details of Car and Accessories of the "America"

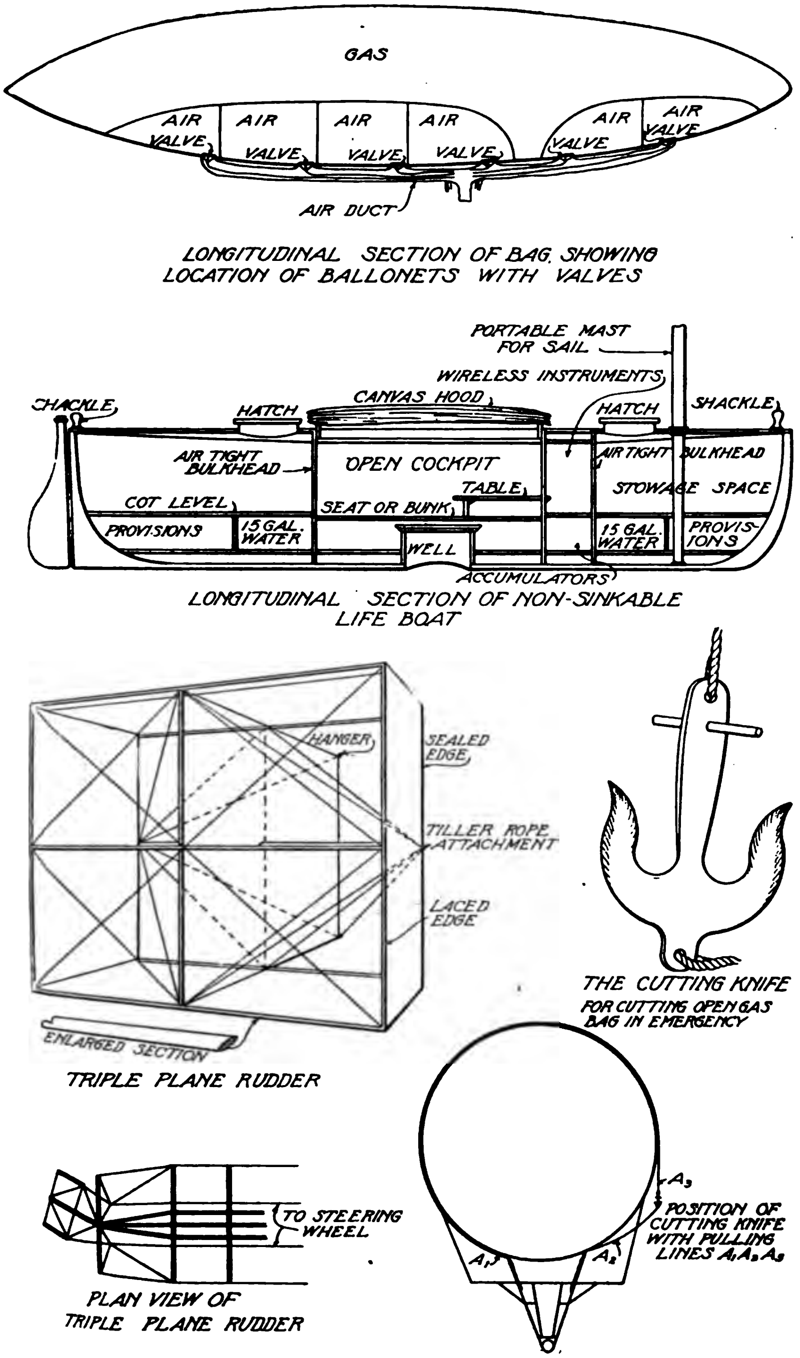

Fig. 23. Details of Balloonets, Lifeboat, Rudders, etc., of Wellman's Airship

term it, was sewed to the fabric about ten feet below the horizontal axis of the balloon. For an emergency descent, there was a "ripping knife," Fig. 23, shaped like an anchor and attached to a rope leading to the car. Pulling this would have cut the gas bag practically in half. From the gasoline tank fore and aft, the bottom chord consisted of tubular extensions. To stiffen the gasoline tank laterally, stays were run from the ends of the extensions to horizontal crosspieces at the ends of the tank and thence back to the body of the tank, Fig. 22. Further reinforcement was obtained by means of numerous wire cable stays, the whole practically forming a bridge which in places was said to be capable of withstanding a stress of as much as 10 tons. No net, or hood, was employed on the gas bag to add to its resistance in motion through the air, the external surface of the balloon being as smooth and tight as a drum head. The car and its machinery were attached to the band on the balloon by 188 hemp lines, attached at as many points on this band and terminating in eyes from which hung the cradle of suspension cables passing under the car. The latter was entirely closed by walls of canvas pierced by several celluloid windows, Figs. 24 and 25, while several canvas bunks were hung from the transverse braces directly beneath the under side of the gas bag, Fig. 22.

Fig. 24. View of Car Showing Propellers and Canvas Covering

Motive Power. The motive power consisted of two engines, the forward one of which was a Lorraine-Dietrich four-cylinder, water-cooled automobile motor rated at 80 to 90 horse-power (the one at the right in Fig. 24) and weighing with its radiator and equipment close to 1,000 pounds. It drove a pair of wood screws, 12 feet in diameter, at 500 r.p.m. The other, Fig. 26, was an E.N.V. eight-cylinder aeronautic motor rated at practically the same power, and driving a second pair of screws 10.5 feet in diameter at a speed of 750 r.p.m. In both cases, the screws were carried on long shafts extending outboard and constituting extensions of the crank shafts of the motors—in other words, they were direct connected. In the case of the after pair of screws, they could be utilized either to propel the ship forward, as shown in Fig. 24, or they could be employed to assist either in its ascent or descent, due to the fact that they were driven through the medium of bevel gearing at the ends of the engine shafts and could be adjusted so as to exert their force in any direction included within an arc of 180 degrees, Fig. 26. This expedient was adopted to take the place of the stabilizing planes usual in French construction, or the sliding weight of Zeppelin's airships. It was

Fig. 25. Close View of Car Showing Windows and Long Gasoline Tank

made possible through the ingenious invention of Chief Engineer Vaniman. As already mentioned, the drive between the shaft and propeller was through miter gears. The shafts themselves were carried in conical supports projecting out from the sides of the car, and these supports were capable of being revolved through the medium of worm gears and hand wheel. As the propeller shaft is turned through an angle, the gear it carries is free to travel on the gear keyed to the power shaft.

In addition to these two motors, there was also a third, or "donkey engine," to revert to marine parlance. This was a small four-cylinder, vertical, water-cooled, gasoline motor rated at 10 to 12 horse-power. It was intended for a number of purposes, one of the most interesting of which was cranking the larger engines to start them. To accomplish this, the donkey engine shaft was geared to the shafts of the larger motors by means of clutches which automatically released as soon as the large motor started. This small engine also served to drive the pumps for inflating the air-balloonets, the arrangement of the latter being clearly shown in Fig. 23. There were six in all, four placed forward and two aft, and all were fed with air from a common duct. Each balloonet, however, was provided with its own individual valve, so that the distribu-

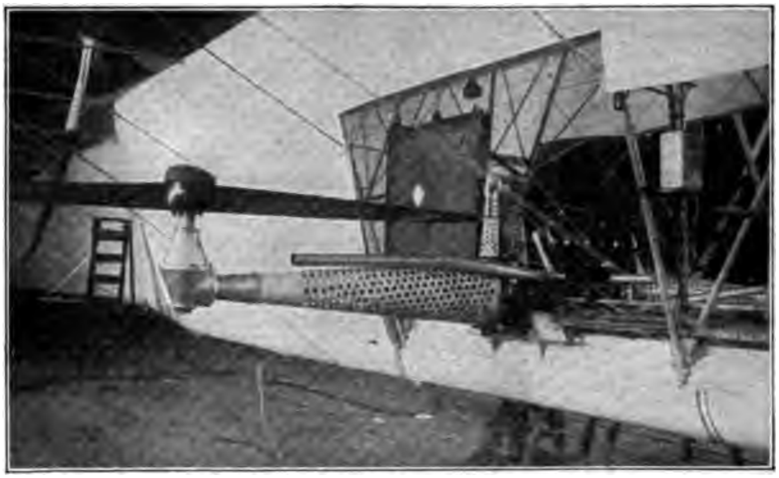

Fig. 26. View of Rear Propellers Set Horizontally for Lifting the Airship

tion of the air ballast could be controlled and the ship kept on an even keel.

Accessories. The rudder consisted of three vertical planes, Fig. 23, the center plane being broader than the other two, which were set back a few feet so that when the rudder was turned sharply to one side or the other, the plane at the inner side of the turn would neither come in contact with the balloon, nor screen the center plane, thereby cutting off its resistance to the air. The bunks already mentioned were only in the form of extra accommodation, the main sleeping quarters being in a lifeboat suspended beneath the car, Fig. 24, and providing accommodation for the crew of six, consisting of Walter Wellman, who was responsible for the undertaking, Melvin Vaniman, chief engineer, Murray Simon, navigator (junior officer of the steamship Oceanic), J. R. Irwin, wireless telegraph operator, and two mechanics. This lifeboat, shown in section in Fig. 23, was specially constructed for the purpose so that while it had an overall length of 27 feet by 6 feet beam, its total weight was only 1,000 pounds. This was accomplished by making the hull of layers of mahogany veneer and canvas, giving it the appearance of being built of solid wood. Two watertight compartments were provided fore and aft, and the boat was self-bailing so that it could keep afloat in the heaviest sea. There was no power in the boat, but a jury mast and sail were carried along, together with an ample stock of provisions and water, so that in case of abandonment it would be possible to keep afloat for a considerable time. Through the center of the boat was an upright steel tube through which the equilibrator passed.

The wireless apparatus of the expedition was installed in a forward compartment of the boat so that it could be employed both while in the air and after the airship had been abandoned. That is, as long as the current held out. The radius of action of the instruments was about 100 miles, and they were provided with current from a small set of storage batteries kept charged by a dynamo driven by the donkey engine. Current from this battery also provided electric lights for the car and boat. In addition to this, there was a telephone system between the boat and car. As it would undoubtedly be necessary to get away quickly in case the airship had to be abandoned in an emergency, the boat was suspended on special self-releasing hooks, so that by cutting a single rope it could be dropped instantly. That this was a ticklish maneuver even under very favorable conditions was shown by the actual rescue of the crew.

It was rendered so by the presence of the equilibrator which did not act quite as effectively in practice as its theory would indicate. Its purpose was to take the place of the usual drag rope carried by the ordinary spherical balloons in drifting. As in view of the tremendous lifting power of the America, it would be necessary to provide a drag rope of considerable weight, advantage was taken of this to make of the equilibrator a sort of automatically compensating balance, hence its name. In fact, it took the place of the ballast ordinarily carried. To give it sufficient weight, it was made of 30 short steel cylinders, each of which was convex at one end and concave at the other, and, as is made clear by the detail view, Fig. 27, the convexity of one tank seated in the concavity of the next, forming a sort of universal joint. This whole series of tanks had longitudinal holes running through their centers and were strung on a heavy steel cable, or flexible wire rope. To prevent one tank from damaging

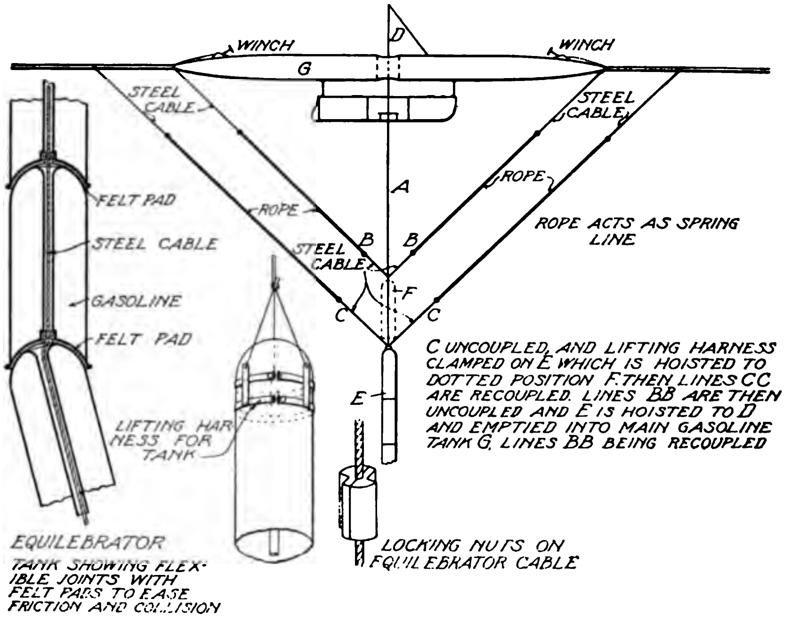

Fig. 27. Diagram Showing Construction of Equilibrator and Method of Suspending it from the Car

the next a felt packing was placed between them and the passage for the cable through the convex portion was flared, or bell-mouthed, so that there would be no danger of shearing the wire rope.

At the end of the series of tanks, a series of 40 wood blocks, each 20 inches long, was strung on the cable, forming a sort of "rat tail" to protect the lower end of the equilibrator by taking the shock of suddenly striking the water. The total length of the equilibrator was 330 feet and the steel tanks were utilized to carry an extra supply of gasoline. The joints between these tanks made it so flexible that, in the space of four tanks, it could be turned at right angles without injury. At its lower end, the wood blocks tapered from about 10 inches in diameter, down to 4 inches at the extremity. Owing to its great length it was utilized as the antennae of the wireless outfit, in addition to carrying a supply of fuel.

The purpose of the equilibrator was to avoid the necessity of carrying sand ballast to counteract temperature changes and eliminate any occasion for permitting gas to escape. The lower end was designed to trail on the water and be supported by it and to guard against losing it in stormy weather, the construction was such as to withstand a heavy sea. This was naturally made necessary by the fact that each of the tanks with its store of gasoline weighed about 100 pounds, making the total weight in excess of 2 tons. The latter was really ballast with a string attached to it, for as the balloon descended more of the equilibrator would rest on the water and a correspondingly increasing percentage of its weight would be water borne, thus relieving the airship and increasing its lifting force in proportion. When the balloon tended to rise, it was first necessary to lift the entire length of the equilibrator out of the water before its height could exceed 330 feet in the air. As soon as this took place, the entire weight of 2 tons or more acted as ballast to prevent the balloon rising to a great height.

To appreciate the importance of this arrangement in its bearing upon the ability of the America to stay in the air, it is necessary to realize what extremely variable atmospheric conditions are met with and what their effect is on the balloon. Hydrogen gas expands or contracts $\frac{1}{491}$ part of its volume for every increase or decrease in temperature of 1°F. Gas within a balloon subjected to hours of warm sunshine will store heat in much the same manner as a green-house does, and when a poor conductor of heat such as rubber is present as in the fabric of America's envelope, this is accentuated as more of the heat is retained and the gas accordingly becomes much warmer than the surrounding air outside. Assuming that the gas reached a temperature of 100° F. during the afternoon, which could hardly be avoided on a bright day even in Fall, and then dropped to 50° during the night, it would involve a contraction equivalent to one-tenth of its volume. This represents an extreme case, but a variation of one-twentieth was quite probable. With the America, that would mean a loss of approximately 1,200 pounds of lifting force. In other words, to prevent settling, an equivalent weight must be subtracted from the load. Coming down would cause an increase in the atmospheric pressure, still further contracting the gas, while a rain storm might augment its load by depositing anywhere from 500 to 1,000 pounds of water on the 4,000 square feet of surface presented by the envelope. Assuming that this has occurred during the night and that the following day is bright, exactly the opposite of these conditions will obtain. The sun will dry out the envelope, expanding the gas until the air is driven out of the balloonets through the automatic pressure valves and the lifting power is greatly increased. There will then be a strong tendency to rise and, under ordinary conditions, the only means of counteracting this would be to permit the escape of gas.

This would reduce the sustaining power of the balloon during the next period of contraction, so that without special means of guarding against the necessity of sacrificing ballast to prevent coming to the earth, and gas to avoid getting too far away from it, the voyage would naturally be limited to a very short period—not more than two or three days at the most. It would also involve carrying a great deal of ballast, thus sacrificing the amount of fuel that could be taken. Were the ship to rise to any great height, there would be the danger of coming down too fast should the gas suddenly begin to contract, and the momentum gained in descending from a great height could be overcome only by relieving it of a great deal of weight.

The equilibrator, on the other hand, was designed to maintain the America between 100 and 200 feet above the water. The ballast automatically "thrown overboard" when the ship dropped lower was again picked up when it was needed and in the same manner. This meant saving gas and augmenting the quantity of fuel that could be carried, making it possible to prolong the voyage from the forty-eight-hour limit otherwise practicable to the eight or ten days that were thought to be necessary to cross the ocean. In theory, the device appeared to be entirely practical. As a matter of fact, this was not the first time it had been tried, having been employed on the original America, in which Wellman made an attempt to reach the North Pole a couple of years previous. In this instance, the conditions were entirely different, one of the chief requirements being an ample supply of provisions, as the explorers might be lost for several months. The equilibrator, therefore, took the form of a long leather tube which constituted the drag rope, and in which the food was carried. The limited experience with it under favorable weather conditions in the Arctic showed that it rode smoothly, and, being a continuous body, it did not offer any substantial resistance when towed. Unfortunately, it dropped into the ocean within two hours after leaving Spitzbergen, thus depriving the expedition of its supplies. This leather food bag was the predecessor of the equilibrator.

To cross the Atlantic, what was most needed was food for the motors. Their combined power only sufficed to drive the America at a speed of 26 miles an hour, while one of them could propel her at the rate of 20 miles an hour. But as each motor consumed 1,000 pounds of gasoline per day, it was intended to keep only one in operation, holding the other in reserve, and also for emergency purposes when necessary to prevent being driven back by contrary winds. With the above speed as the basis, it would require six days to cross the Atlantic in a perfect calm or its equivalent, *i. e.*, the favoring winds of one day neutralizing the contrary air currents of other days. To allow ample margin, ten days travel was provided for, thus making it necessary to carry 10,000 pounds of gasoline, or 5 tons. Of this quantity 4 tons were carried in the steel tank forming the foundation of the car, and the remaining 2,000 pounds in the equilibrator.

The equilibrator passed down through the center of the car, and through a well in the center of the lifeboat, as shown in Fig. 22. It was supported by a pair of steel cables running forward and another pair running aft. To provide a certain amount of flexibility, sections of Manila rope were introduced into the steel cables as indicated. To be able to utilize the supply of gasoline in the tanks, a pair of winches, Figs. 22 and 27, were provided to haul the upper pair of cables in, taking the strain off the lower pair so that they could be disconnected by a number of the crew let down in a "bosun's chair." The uppermost tank was then hoisted and the cables made fast again below it. Then the upper cables were slackened and detached to permit of drawing the tank up into the car. Contrary to what might appear to take place, in pulling in on the winches, the equilibrator would not be hoisted but the airship drawn down.

In the forward end of the car was placed the navigator's bridge, where the compass, leeway indicator, and the steering wheel were placed, the latter being connected by light steel cables to the triplane rudder of steel tubing and canvas. Here also were placed the meteorograph, an instrument to record combined atmospheric phenomena, the barograph (altitude recorder), and the thermograph (recording thermometer), as well as the statoscope (a form of aneroid barometer having a large air reservoir and highly responsive to minute fluctuations in pressure). Speaking tubes led aft to the engine room. The problem of navigating the ship was naturally no easy matter. While its position would be ascertained from time to time in the usual manner, by the aid of the sextant and chronometer, its actual course at any time would be hard to determine. For instance, if it were traveling east at 20 miles an hour, and the wind were blowing south at the same speed, its actual course would be southeast, although the compass indication would be east. Wind vanes or similar instruments would be of no assistance as they would have no connection with the sea as a basis from which to determine the direction of motion, though this could be obtained by means of a log line let down from the lifeboat. As it was not desired to reach any particular port, there was no great necessity for accuracy in navigation, the only aim being to get across the ocean.

Akron. It was with no feeling of regret that Melvin Vaniman, leaning over the taffrail of the steamer Trent, watched the ill-fated America sink slowly to the sea. It might be supposed that the engineer who had spent so many years of work on this dirigible would entertain some sentimental regard for the old balloon. But Vaniman's thoughts were already centered on another expedition in which he would not be hampered with old material, an old gas bag and old engines, but could plan an entirely new airship made of brand new material and exactly as he wanted it. The America had served its purpose well, and from her the lessons had been learned that were necessary to make a future airship successful.

When the America was abandoned, it was structurally sound, showing that the principles involved were correct. One part only had failed: A key worked loose in one of the propellers, as already described, depriving the airship of the use of the horizontal propellers, and to this defect Vaniman attributed the failure of the expedition. Contrary to public opinion, Vaniman's faith in the equilibrator, or its equivalent, was not shaken. Its action in the sea, its defects and good qualities were all known after this voyage, and it was from this experience that he got to the heart of the problem, viz, the designing of a device that would serve the purpose of the old equilibrator without the latter's defects—a device that would have changeable and not a fixed weight, in other words, an equilibrator that could be made heavy or light at will.

The new expedition has been financed by F. A. Sieberling, president of a large rubber goods manufacturing concern, and the envelope of the Akron was made in the Ohio city after which it is named, under Vaniman's personal direction. It differs considerably from that of the America, being much longer and of smaller diameter, Fig. 28, with a tapering stern, instead of the former blunt-nosed, double-ended form. The old hangar at Atlantic City was impressed into service again, but the 268-foot length of the new ship exceeded its housing capacity by 10 feet, and, rather than enlarge the building, which could have been done only at considerable expense, this much of the balloon was sacrificed, the dimensions of the latter thus being 258 feet overall, by 47 feet in diameter. Below the balloon is suspended a car similar in shape to that of the America, but considerably longer. The body of this car forms a steel tank capable of carrying 5 tons of gasoline, and on this tank a platform constituting the floor of the car is built. To drive the airship, three engines are provided, one of 100 horse-power, placed forward and fitted with two propellers adapted to revolve only in a vertical plane, and two others of 100 and 80 horse-power, respectively, farther aft. These two motors are fitted with propellers which may be revolved at any angle between the vertical and horizontal planes,

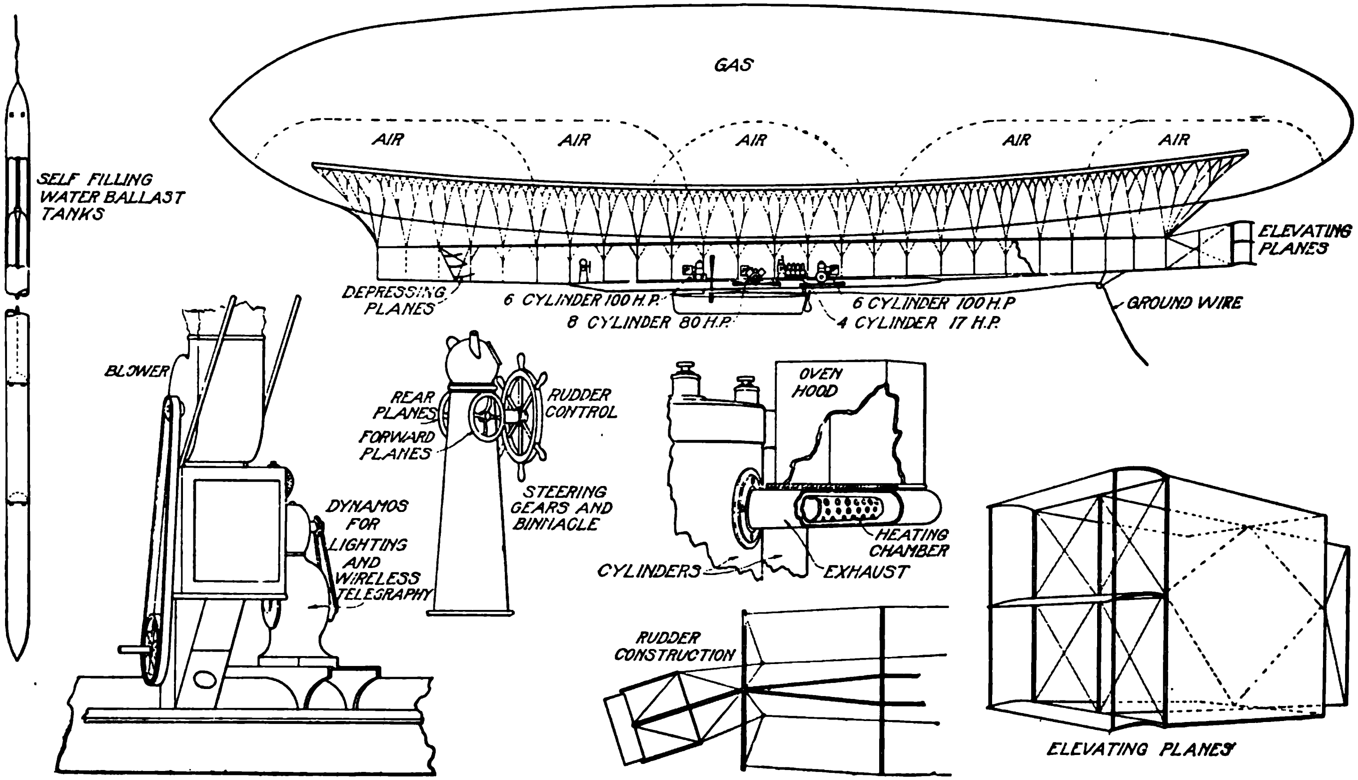

Fig. 28. Diagram of Vaniman's Airship "Akron" Showing Details of Some Novel Control Devices

being adjustable through an arc of 180 degrees by the aid of a bevel driving arrangement similar to that on the America, and designed to enable the thrust of these propellers to be utilized for raising or lowering the airship. Normally, only the forward motor will be employed to drive the ship ahead and, from the results of the short trial trips made, there seemed to be no reason for believing that the speed of 30 miles an hour for which the ship was designed when running under this one motor, would not be realized. Under full load, this motor consumes about 60 pounds of gasoline per hour, so that the supply of 5 tons should last a week.

When utilizing the forward motor alone for driving, the propellers of the other two motors will be feathered, or adjusted horizontally so as to present the minimum surface to the wind, thus keeping down the head resistance. In addition to the engines in question, there is also a 17-horse-power motor directly coupled to a dynamo to supply electric current for lighting and for the Marconi wireless equipment, Fig. 28. It also operates the blower for filling the air balloonets and drives a countershaft from which any of the larger engines can be started by power. Two of the larger motors are of the six-cylinder type, the other being an eight-cylinder, while the auxiliary motor is a four. Benefiting from the experience on the America, the envelope of which was in constant danger of being set afire from the exhaust of the motors, the engines of the Akron are equipped with specially-designed mufflers attached directly to the manifold. One of them is fitted with an oven for use in cooking, Fig. 28.

Substitute for the Equilibrator. According to Vaniman the crux of the problem lies in the ability to keep the airship down at a moderate level. It is an easy matter to design an airship that will have sufficient carrying capacity to cross the Atlantic, but the difficulty is to maintain the airship at a constant moderate elevation above the water during the voyage. The equilibrator having failed signally to do this in accordance with its theoretical promises, it has been abandoned, and the height of the Akron is designed to be controlled by taking on water ballast; also by the use of stabilizing planes fore and aft, while in case of emergency, the elevating and depressing propellers, which have been doubled in number and power, can be resorted to. As shown by the sketches, Fig. 28, there are three planes on each side of the car, those forward being curved upward, thus constituting depressing planes, while those at the rear are curved downward and are designed to be employed as elevators. The latter are mounted on the rudder. These planes may be tilted to any angle desired and serve to keep the airship on an even keel. When dipping down to take water, the forward planes will be used for depressing the bow, and the rear planes for elevating the stern. These planes are separately controlled by hand wheels on either side of the binnacle, as shown in the detailed sketches of the steering gear in Fig. 28. The level of the ship may further be controlled to a considerable extent by inflating the balloonets forward at the expense of those in the rear, when it is desired to make the bow heavier than the stern, and *vice versa*. To scoop up water ballast, it will be necessary to drive the ship down near the level of the ocean, which may be done by tilting either pair of adjustable propellers to the proper angle. The only object in having two sets of adjustable propellers is to provide an extra set for reserve. The device with which water ballast is scooped up is somewhat similar to the equilibrator used by Wellman. It consists of tanks about 6 inches in diameter and 24 inches long, strung upon cables exactly as were the gasoline tanks of the equilibrator, Fig. 28. These ballast tanks are provided with openings near the upper end of each so that by dragging them in the sea, they will scoop up water. There will be three sets of tanks strung on separate cables, and under normal conditions they will not hang from the car as did the equilibrator, but will be stored in the body of the vessel. When taking up water for ballast, if the wind be strong, the airship will be headed into the wind and the tanks will be trailed from a point aft of amidships, so there will be no tendency for the airship to nose down into the sea. It is planned to maintain the Akron at an elevation of between 200 and 1,000 feet at the outset of the voyage, but as the airship is lightened by the consumption of gasoline and provisions, it may rise to much greater heights. During the daytime, it will have to be heavily water-ballasted in order to hold down to these levels when the gas in the balloon is expanded by the heat of the sun. At night, this ballast will be emptied overboard to compensate for contraction and the consequent reduced lifting capacity of the balloon.

Suspended below the Akron is the same lifeboat in which the crew of the America made their escape, but its construction has been materially altered to facilitate launching as well as the greater comfort of the crew. The well in the center has been eliminated as there is no longer any equilibrator to pass down through it. A much larger wireless equipment with a sending range of 500 miles is also installed in the boat, a ground being provided by trailing a wire in the sea. The crew of the Akron numbers seven men all told, consisting of the commander, navigator, helmsman, wireless operator, two engineers, and one extra man for general work. Provisions are carried for a cruise of twenty days. The original intention was to start in October, 1911, but so many causes of delay arose that the Akron was not ready for its first trial trip until November. Several trial trips were made, one or two of which were marred by slight accidents, though generally successful, so that it was decided to postpone the start until the following spring.

The navigation of a dirigible is a much more difficult thing than that of a steamer, as both the speed and the direction of travel are more or less uncertain. Had it not been for the equilibrator dragging in the water, the crew of the America would not have known that she was traveling broadside on, after the motors were finally stopped for good, nor how fast they were going. In fact, as the dirigible without its motors is simply an old-type balloon that drifts with the wind as if it were a part of it, there is no sensation of movement whatever and naturally none of direction when over the open sea, for want of fixed objects to use as points of observation. In this connection, Vaniman has devised a number of interesting instruments which will indicate the direction of travel and likewise the speed of the airship. One of these consists of a combined camera and compass, the camera having its ground glass divided into equal squares. By noting how long a "fixed object" on the water below takes to pass across a given number of squares, in connection with the altitude as indicated by the barometer, it will be possible to calculate definitely by means of triangulation the speed at which the vessel is traveling, and, by reference to the compass, the direction of travel. At first sight, it would seem as if this method would fail for want of a fixed object to observe, but it will be recalled that though waves travel, the water that forms them is practically stationary. Hence, the foam of a white cap may be considered as practically a stationary object while it lasts. In addition, Vaniman has also developed a special type of sextant for use on the expedition.

"Wire-Wound" Fabric. The fabric employed in the making of the envelope of the Akron is said to be the strongest ever employed for the purpose, so that by continually pumping air into the balloonets, air ballast can be added and the ship brought down from a considerable height. The value of this feature was strikingly shown in one of the trial trips when the airship was brought down in this manner from a height of 2,000 feet, after an accident to one motor and the breaking of the propeller shaft of another.

This powerful control over the gas led Vaniman to make a further study of the subject and he calculated the strength of a fabric necessary to resist the increased pressure in the envelope due to a rise in temperature of 50 degrees F. With only a small factor of safety, it was found that the tensile strength necessary was 1,000 pounds to the square inch, or 18 tons to the yard. To obtain this increased strength, a special fabric interwoven with fine piano wire must be employed, the wires running longitudinally and circumferentially without cuts or joints, so that their maximum tensile strength may be relied upon, the longitudinal wires being spaced $\frac{1}{16}$ inch and the circumferential wires $\frac{1}{32}$ inch apart. This fine mesh renders the envelope both fireproof and lightning-proof on the principle of Davy's safety lamp, while this great wire cage will doubtless serve as an excellent antenna for wireless work. On an airship of the Akron's size, the increased weight due to the wire is about $2\frac{1}{2}$ tons.

The additional weight of the wire would reduce the net lifting power of a ship of this size from $7\frac{1}{2}$ tons to 5 tons, but the advantages obtained would warrant the sacrifice. In comparison with the weight of the rigid dirigible construction, this net carrying capacity is remarkable. The latest Zeppelin built in 1911, the Schwaben, with 680,000 cubic feet of gas, has a net lifting capacity of $2\frac{1}{2}$ tons, while a ship of the size of the Akron with a steel-reinforced gas bag holding only 400,000 cubic feet of gas would have a net capacity of 5 tons. The ability of the "wire-wound" envelope to withstand such heavy pressures would automatically take care of the great problem of expansion and contraction, giving a powerful control by enabling the pilot to change altitude without loss of gas or ballast and without depending upon planes or motive power.

Vaniman plans to build a dirigible of the size of the Akron, using this new "wire-wound" fabric during 1912.

Inflating the Akron. As the new Vaniman airship has a capacity of 400,000 cubic feet of gas, no small problem was involved in the manufacture of sufficient pure hydrogen gas to properly inflate it, as the lifting power of the gas is not alone proportional to its purity, but the presence of acid fumes or other adulterants would be ruinous to the fabric of the envelope and particularly to the numerous seams. To carry out this important undertaking a special plant was built just outside of the big shed at Atlantic City. Making allowance for waste and condensation, sufficient material was purchased to manufacture 450,000 cubic feet of hydrogen. This consisted of 80 tons of scrap iron and 100 tons of sulphuric acid. It will be noted that Vaniman has introduced a number of innovations in this gas plant, as compared with the usual method, so that there is no interruption in the generating process. As shown in the plan view, Fig. 29, there are four generator tanks *A*, made of wood with all iron parts well coated with pitch to prevent their being attacked by the acid. These tanks are partly filled with scrap iron, Fig. 30. The sulphuric acid is fed from one of the two large reservoirs *B*, Fig. 29. Running over these reservoirs is a track *C*, on which the sulphuric

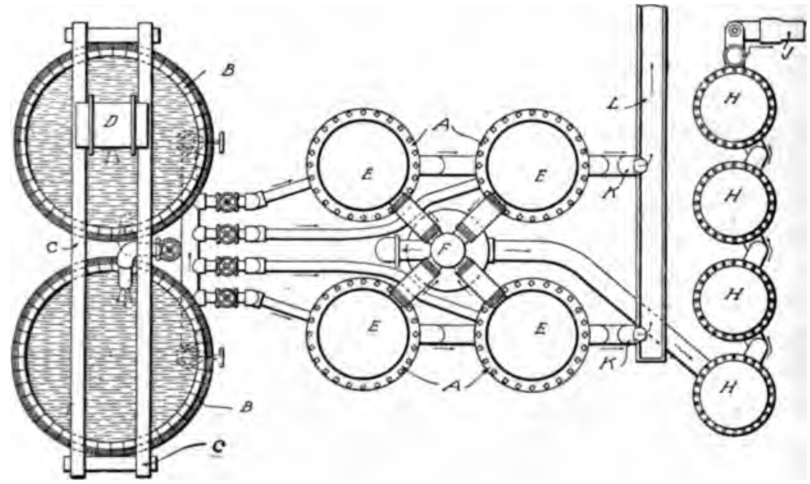

Fig. 29. Plan View of Vaniman's Hydrogen-Generating Plant

acid casks *D* are supported. To prevent too rapid generation of gas and the choking of the tanks with ferrous sulphate, the acid is diluted in the proportion of one part to eleven parts water. While this mixture is being prepared in one of the reservoirs the supply is drawn from the other. This solution takes the course indicated by the arrows to the bottom of the generator tanks, and it may be caused to flow directly into any one of these tanks or from one pair of tanks to the other, this being a more economical method as it insures complete utilization of every bit of the acid. The gas generated in the tanks rises to the top, where it is trapped by the gasometers *E*

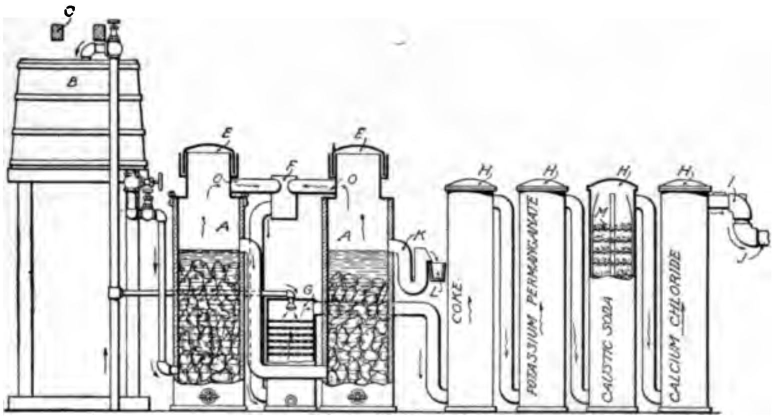

Fig. 30. Side View of Vaniman's Hydrogen-Generating Plant, Somewhat Distorted to Bring Purifying Tanks into View

and flowing into a common chamber *F* passes down to the washer *G*, Fig. 30. Here it is forced to pass upward through a series of perforated plates, while a spray of water flows downward through the same plates. Thence, the gas passes through four tanks *H*, the first containing coke, the second potassium permanganate, the third caustic soda, and the fourth calcium chloride. The first two serve to purify the gas of such materials as arsenic, sulphur, and phosphorus which are likely to be picked up from the iron. The other two tanks serve to remove all traces of moisture from the gas.

Hydrogen is an odorless, colorless gas and it would be impossible to detect leaks in the balloon were not some means employed to impart an odor to the gas. The "perfume" commonly used is muronine. This is placed on a sponge in the pipe *I*, and thence the gas is fed directly into the balloon at the tube *J*. The substance in question has a most penetrating, sickish odor that can be readily detected, no matter how small the leak may be.

One of the advantages of the arrangement of this plant is that when it is desired to charge one of the generators with fresh scrap iron, it may be cut out of the system completely by shutting the valve in its connection and by clamping the rubber hose connecting the gasometer of that particular generator with the chamber *F*. The spent solution flows from the generators through traps *K* to a trough *L*, which leads to a large drain. Heretofore, the purifying and drying tanks have been filled with coke on which the various cleansing chemicals were sprinkled, the purpose of the coke being to prevent the materials from clogging. This method has caused much trouble as the materials would slowly gravitate to the bottom of the tank, choking the flow of gas. Whenever such a condition arose, it was necessary to shut down the entire plant and clean out the tanks. Vaniman employs instead a set of trays of copper netting secured to iron straps, as indicated at *M* in Fig. 30, and on these trays the purifying and drying materials are placed. Thus the mass is kept in a porous condition, through which the gas can easily percolate, and, in case of any trouble, the entire set of trays can be lifted out bodily. It was necessary to operate the plant for five days and nights continuously, the hydrogen weighing more than a ton, or about half as much as that of the three-ply cotton and rubber fabric of the envelope. Some idea of what this amount of gas means may be gained from the fact that its equivalent in coal gas fed to an ordinary five-foot burner would supply it for more than ten years constant burning. The lower part of the illustration shows a true plan view of the gas-generating plant, while the upper part is a somewhat distorted section, drawn in this manner to more clearly illustrate the passage of the gas in the course of its generation and purification. The cost of this plant, plus that of the material necessary to inflate the Akron but once, would be sufficient to pay for several modern aeroplanes.

ACHIEVEMENTS OF THE DIRIGIBLE

The year 1910 will go down in history, not alone as marking the first actual transportation of passengers through the air for hire, but likewise the first attempts to cross the Atlantic in an airship. Two of these attempts were proposed and one was actually undertaken. This was the ill-fated cruise of the America, already described, but the failure of its promoters to achieve their object has proven no deterrent to others intent upon accomplishing the same feat. In fact, 1910 may be said to mark the beginning of an era of aerial transportation, as while the wreck of the Zeppelin after having made but comparatively few trips, put a sudden end to the much advertised "regular passenger service" for the time being, neither this nor the subsequent wrecking of other Zeppelin airships proved sufficient to discourage the promoters. During 1911, the Zeppelin and several other German companies formed for the purpose carried hundreds of passengers, and it is a fact worthy of note that since the latter part of that year, one of the large steamship companies has combined announcements of aerial trips with those of the sailing of its steamers; and tickets good for flights in Germany can be bought in this country. The success of the German dirigible passenger service has been such that, in spite of the numerous disasters which have fortunately been free from fatalities, a similar service is to be instituted in this country, using German airships at first.

Wellman's Expedition. Owing to its novelty, as well as its daring, the attempt of Wellman to cross the Atlantic in the America, is worthy of record, particularly as his failure has not deterred others from attempting the same feat, and doubtless it will not be very long before it is actually accomplished. What such an accomplishment will show, however, apart from the fact that the aeronauts met unusually favorable conditions, is questionable. In order that the appended account may be free from the sensational coloring given the America's trip by the newspaper and magazine reports, excerpts are taken from the story of Vaniman, the chief engineer, though it is to be noted that his version exhibits some irreconcilable differences with that of Wellman himself.

The start was made at 8 A.M., October 15, 1910, from Atlantic City in a light southwesterly breeze, there being considerable fog.

The attempt was really premature and probably would not have been made at that time, had it not been for the question of good faith on the part of Wellman raised by the press. So many delays had been experienced that the date of starting had been constantly postponed from month to month and Wellman was accused by inference, if not openly, that he had no intention whatever of ever making the attempt. The actual start was accordingly made under unfavorable conditions and without any previous trials of the airship that would doubtless have revealed the defects later brought to light when there was no possibility of remedying them. Everything had apparently been in a state of readiness for weeks prior to the start, but this was not actually the case, and while numerous indoor tests of the machinery had been made this was not the equivalent of actual trials in the open. The "after" engine, as already explained, was arranged to drive its two propellers through the medium of bevel gearing so that the propeller shafts, which were at right angles to the extended shafts coupled to the engine, could be swung bodily about in a complete circle, thus making it possible to employ their thrust in any direction desired, but more particularly in a vertical line so as to force the balloon up or down. The fatal mistake consisted in not supplying this engine with a flywheel. For four hours it operated steadily, not missing more than two explosions in this entire period, but the absence of the flywheel (for which it had been designed and the loss of which was not compensated for by the propellers) produced a pounding action, and the keys of the bevel gearing worked loose, rendering the engine useless. How serious this loss was could not be appreciated until the next day, as will presently be explained.

During Saturday evening the airship was in danger of being blown onto the shore of Long Island by a southerly shift of the wind, and it was necessary to use the engine to keep her headed off shore. The fog still persisted and it was feared that the two-ton equilibrator trailing in the water would strike some vessel, resulting in immediate disaster to the airship, as it would draw it down into the sea; furthermore, it might do a great deal of damage to the vessel encountered. The moon was full but owing to the fog it was impossible to see anything ahead. Two lookouts were stationed to endeavor to prevent collisions. Suddenly the sound of a fog horn was heard, and almost immediately the masthead of a schooner loomed up dead ahead. But the airship responded beautifully to its helm and swung to one side, just clearing the vessel by a narrow margin. This experience as recounted later by the captain of the vessel was most thrilling. He had no knowledge of any contemplated voyage across the ocean by airships, and he was greatly frightened when the monster loomed up out of the fog with the sparks streaming from its red-hot exhaust pipes and making a terrific racket with its unmuffled engine. The lashing equilibrator with one tank empty, owing to leakage of gasoline, was being pounded by the water, giving a weird, hollow sound that added greatly to the terror of the crew. This was the only approach to a collision experienced.

Vaniman had no idea that the engine was throwing sparks until this was revealed by the darkness. The exhaust pipe terminated directly back of the propellers, so that the sparks were carried off in the wake of the latter and there was little likelihood of their lodging in the fabric of the balloon. The airship had been traveling through fog ever since morning and was dripping wet, so there was no danger of fire. Sunday morning, the fog still continued and the wind, veering to the west, began to freshen, making it unnecessary to use the engine. But with the freshening of the wind a new danger arose. The airship had started out from Atlantic City with an extra supply of gasoline aboard, so that it hung very low over the water, all but six tanks of the thirty in the equilibrator being submerged. With the freshening wind, it was found necessary to throw over gasoline in order to lighten the airship. Had this gasoline been left behind to start with, the airship would have made much better progress and would have been much farther along when the wind freshened, but the extra fuel was taken on with the expectation that the fog would eventually lift, and under the heat of the sun the gas in the balloon would expand and lift the balloon to its normal position. However, the sun remained hidden by banks of fog.

Sunday afternoon, the wind assumed a velocity of 35 miles an hour. The night grew very cold, shrinking the balloon and making it necessary to throw out more gasoline. Then a peculiar motion began to manifest itself. It will be recalled that the purpose of the equilibrator was to hold the airship at a practically constant level above the sea; in other words, the airship and the sea were to divide between them the burden of supporting the two-ton equilibrator. If the ship showed a tendency to rise, it would be weighted down by having to lift a greater weight off the sea, and if it showed a tendency to descend, it would be lightened by letting more of the equilibrator float, with the result that the airship should be held at a practically uniform elevation above the water. However, when the wind freshened, the drag of the equilibrator began to set up a surging motion. It would pull the airship down, slowly but surely, until it almost touched the water, then the airship would rebound with gathering momentum, pulling the equilibrator out of the water, tank by tank, until it was lifted entirely clear of the surface. The equilibrator would then swing forward like a huge pendulum and, as its weight overcame the buoyancy of the balloon, it would strike the water, and the dragging action would recommence. In this way, the airship kept constantly oscillating up and down, the period of the oscillations being about ten minutes. On one occasion the big balloon swung so near the water that the waves struck the lifeboat cradled below it. There seemed to be no way of preventing this. It was then that Vaniman realized the loss of his after motor, for had he been able to use these propellers to lift the airship when it showed a tendency to be dragged down, the oscillation could have been largely, if not entirely, prevented.

The thrust of the propellers which might thus have been used was 800 pounds, and this would have been more than sufficient to correct the surging movement. Had the airship been further lightened, it might have been able to lift the equilibrator clear of the water when there would have been no drag to contend with and it would have been possible to steer the craft into the wind. As it was, the airship was helpless. It was drifting broadside to the wind. As long as the oscillatory motion kept up, it would have been dangerous to have headed the vessel into the wind, for then it would have pitched badly, tending to stand straight up and down. As long as the wind held from the right quarter, it mattered little whether the engine was used or not, but the oscillations were nerve racking, and not at all calculated to inspire the crew with any feeling of security. The pounding of the waves on the equilibrator, about which so much was published, amounted to practically nothing, according to Vaniman. The jars were not at all serious, but considering the experiences they had gone through, the members of the crew were ready to exaggerate the slightest unusual shock, and the harmless pounding appeared to assume dangerous proportions.

Sunday was a night of grave apprehension. It was found necessary to throw over a quantity of the precious gasoline, as well as the damaged engine (a 90-horse-power automobile motor) in an effort to prevent the airship from being dragged down into the water. Monday, however, the sun rose clear and hot and beat upon the gas bag. There was no wind to counteract the heating effect, because the vessel was drifting with the wind, and the gas heated rapidly and expanded so quickly that it lifted the balloon and its heavy equilibrator to an altitude of 3,000 feet before it could be checked. The rise was so rapid as to make the crew dizzy and affect their ear drums. Vaniman opened the valves to let out the hydrogen, meanwhile closely watching the statoscope for the first signs of descent. Despite the utmost precautions and the careful handling of the valves, the descent took place quite as suddenly as the ascent. As the balloon fell it gathered momentum and also lost buoyancy, due to the contraction of the gas bag in the increasing density of the lower strata of air. This contraction of the gas bag produced a constant downward accelerating force, greatly increasing the speed of the descent. However, the equilibrator served as a cushion to ease the fall. It entered the water at high speed and sank until the last can was submerged before the airship, relieved of its weight, could recover and rise again. This one experience was sufficient to show the value of the equilibrator.

Had there been no device of this nature provided, the airship must, inevitably, have been carried into the sea at the end of its downward plunge, striking the water at such a velocity as to have crushed out the lives of all on board. Had the airship started without an equilibrator, it would frequently have been necessary to throw over ballast to prevent such descents, and it would as frequently have been necessary to open the gas valves to prevent ascension to dangerously high altitudes. It was Vaniman's opinion that without the equilibrator the airship could not have kept afloat a single day. As it was, this single ascent cost fully one-seventeenth of the total supply of gas.

Monday, the third day out, the sailing was good; but the wind had veered around to such a direction as to drive the airship southward. It was then planned to head for the Azores Islands, and later in the day a still further shift of the wind made it necessary to head for Bermuda. The oscillatory motion continued under the action of the wind and it was necessary to lighten the balloon of still more gasoline.

When, early in the morning of Tuesday, the lights of the Trent were made out, it was decided that it would be foolish to continue the voyage farther. There remained but little gasoline in the main tank and much of the gas in the balloon had been wasted. There was every probability that the airship could keep afloat during the day, but the chances of staying in the air at night, when the reduced gas supply in the envelope would be condensed by the cold, were rather slim. Furthermore, there was the difficulty of launching the lifeboat with the heavy equilibrator trailing in its wake, and it seemed far more prudent to undertake to launch the boat while a vessel stood by ready to give assistance.

The problem of launching the boat was no small one. The airship was drifting at the rate of 15 knots, broadside to the wind, as may be seen by noting the angle which the white trail of the equilibrator makes with the shadow of the gas bag in the illustration, Fig. 31, taken from the deck of the Trent. This meant that the boat, which could not be swung athwart the car, would have to be launched sideways. The valves were opened until the boat dropped to within 4 feet of the water. All the materials that were saved from the airship were stowed in the bottom of the lifeboat to act as ballast. At a given signal, the automatic shackles which held the boat to the airship were released and the boat dropped into the sea. Despite the fact that it was traveling broadside at a rate of 15 knots, it did not ship a gallon of water. As soon as the balloon was released of this weight, it shot up into the air and the equilibrator was whipped out of the water, striking the boat and crushing the forward air compartment, fortunately above the water line. Before cutting loose from the airship, Vaniman tied a can to the gas valve of the balloon so that the latter would lose its gas, thus obviating any danger of its rising out of the sea and acting as a menace to the rigging of vessels at sea or buildings along the coast. When last seen, the balloon was settling, nose down, into the water.

Thus ended one of the most remarkable voyages ever undertaken, and certainly the most remarkable rescue at sea. The results accomplished were two records for dirigibles: One of duration which consisted of 71½ hours in the air, as against 36 hours, which was made by Zeppelin; and the other of distance, which was put at 1,008 miles by navigator Simon in his logbook, the previous distance record having been made by Zeppelin when he covered 800 miles without coming to earth. However, the object of the expedition was not to establish records. The underlying idea of Wellman and Vaniman has been to stimulate interest in dirigible balloons, to study their behavior under varying conditions, and to promote their development. It is a tribute to the skill of the engineer who designed the America that on its first voyage, without any preliminary trial, it broke all previous records, and, as far as the machinery is concerned, with the exception of the one defective engine, maintained

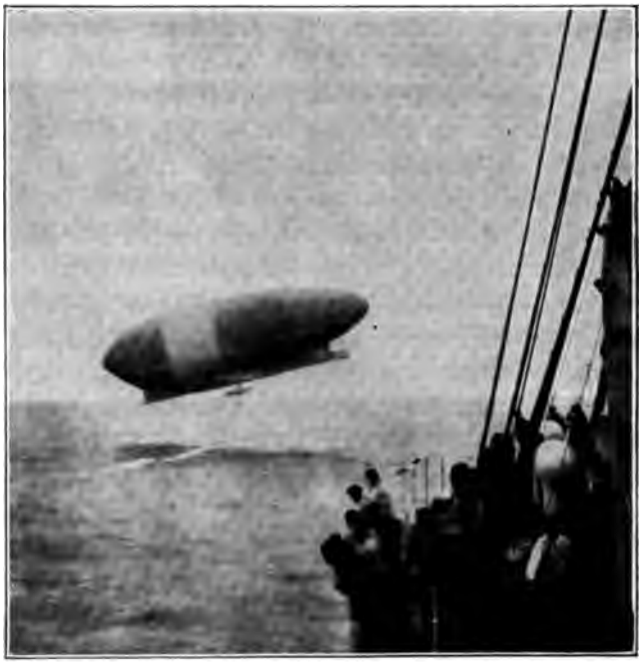

Fig. 31. View of the "America" Settling into the Sea Prior to the Release of the Lifeboat. Picture Taken from the Deck of the S. S. Trent

every part intact. Not a stay was broken and not a nut needed tightening during the voyage.

Brucker's Proposed Expedition. Wellman's contemporary, who intended to attempt a transatlantic voyage by dirigible in 1910, is Joseph Brucker, a German-American, whose project antedates Wellman's attempt. Owing to delays in getting ready, it was impossible to start before too late in the season—now it is proposed to carry out the expedition early in the Spring of 1912, but along somewhat different lines. Before describing Brucker's apparatus, a brief resumé of his comments on the reasons for Wellman's failure will be of interest. He says, quoting from *Umschau*, Berlin:

> I have repeatedly pointed out that in the present state of the art it will be impossible to cross the Atlantic in an airship north of the 35th parallel of latitude, because in that region one depression follows another, and particularly in the fall. Wellman was meteorologically ill-advised. At the time of his start, it was well known that a violent hurricane was raging in Cuba, and that such violent disturbances of the atmosphere in those latitudes are followed by extraordinary collateral phenomena in latitudes 35 to 40 degrees north. Wellman's chart of the journey confirms this.
>
> It also seems that Wellman could not rely on his motors—one was disabled soon after he set out and the other was probably not powerful enough to enable the America to keep a more easterly course. The America seems to have traveled more like a free balloon, for which reason this performance should not be regarded as a record for dirigibles. Wellman would in all probability hardly maintain that he could follow a definite course. Another fatal error was the equilibrator, to which Engineer Vaniman pinned his faith. This was in itself a very cumbrous contrivance with its thirty gasoline tanks and turned out to be a source of danger.
>
> Dr. Alt, of the Munich Meteorological Station, and I have made many experiments during the last few months with arrangements similar to Wellman's equilibrator. We have given the tanks most diverse forms, only to come to the conclusion that all such devices, when an airship is traveling over water, not only produce enormous resistance, but are highly dangerous to the airship itself. The America seems to have perished from appendicitis. A surgical operation, however, could not be performed, because the airship, if it had been relieved of this burden, would have risen to an enormous height and would have faced new dangers.
>
> The expedition which I have organized is the result of scientific study. It is our intention to start from the Cape Verde Islands, about 2,350 miles from the Lesser Antilles. There are no counter winds in our course, no fogs, no storms, and, therefore, it should be possible to travel with the wind at a rate of about 7 meters (23 feet) per second or 15 miles an hour.

Brucker's selection of a route founded on taking advantage of a prevailing trade wind is not new. Edgar Allan Poe suggested the plan of sending a balloon drifting with the trade winds from Africa to America, in one of his realistic novels. In France, it had been seriously proposed even prior to this, and it was again taken up in the late nineties when Santos-Dumont was keeping interest in aeronautics alive in Europe by his experiments. Strange as it may appear, the first development of the dirigible caused these projects to be forgotten, for, with its aid, the primary idea was that the wind was to be overcome and not taken advantage of as in the spherical balloon. The chief remedy sought was increased speed, while Zeppelin's sole idea was to increase the radius of action in order that an airship might be capable of outlasting a storm.

To finance his project, Brucker incorporated the *Transatlantische Flug Expedition*, with a board of directors comprising some of the foremost scientific and commercial leaders of Germany. The stock has been subscribed by a number of individuals, though the Swiss chocolate manufacturing firm "Suchard" has guaranteed to meet most of the expense, hence, the name.

Type of Balloon. The balloon is of the type of the Parseval VI, but modified. It measures about 240 feet in length by 68 feet maximum diameter, which is at the first third of its total length, as in the Parseval. The bow is spheroid, or egg-shaped, while the stern is sharply pointed. The envelope has a capacity of 9,400 cubic meters (more than 330,000 cubic feet), the balloonet representing more than a third of this, or 3,500 cubic meters, which is equal to the total displacement of a typical French airship. This insures a rigid hull, even after an extensive loss of gas, enabling the ship to meet the most extreme conditions that are apt to rise in a long voyage. Efforts have been made to give not only a tremendous radius of action, but also the highest attainable degree of safety. Both of these requirements have been realized by building a ship of ample size designed for low speed. The weight thus saved is utilized to make a thoroughly strong structure and in equipping the vessel with safety appliances. In fact, the craft represents the very latest product of the German aerial dockyards.

The envelope is made of a special fabric consisting of three layers of cloth, two of rubber, and a light rubber coating on both surfaces. This, together with the large volume, and the ratio of four to one between length and diameter, resulting in a comparatively small surface per unit volume, should give excellent gas-retaining qualities. Even the Zeppelin VI, which was burned at Baden-Baden, retained its gas for many weeks at a time, although in daily service. In the Suchard, gas loss by diffusion will be negligible as compared with the amount escaping when the safety valves are opened under the tropical sun. This loss is to be minimized by a special patented device, which is perhaps the most important feature of the design of the entire apparatus.

Novel Features. Advantage has been taken of the fact that the route will be entirely over water. The plan is to scoop ballast from the ocean whenever needed by means of buckets on a steel cable. These buckets are of sheet steel of a shape to give the minimum resistance when filling. Each holds seven to eight gallons and has four holes in front to permit the water to enter, filling quickly and automatically by reason of the motion of the airship. Although they can be dropped into the water so that their action takes place immediately, the effect of the sun's rays is also very sudden, and dependence is not placed on this device alone. It is supplemented by a *movable weight,* the position of which regulates the inclination of the keel. With the aid of this arrangement, a certain amount of downward force can be called into play by aeroplane action through the forward movement of the vessel. It practically amounts to changing the angle of incidence as is done in an aeroplane with tbe elevating rudder.

But the most important feature is an original *device for cooling the envelope with running water.* Light canvas hose extends from the boat to the top of the balloon, where it encircles the gas valve and then extends back along the balloon in both directions. It is provided with a number of perforations along its sides, ending in a hard-rubber spray nozzle fore and aft. From a tank in the boat, water is pumped through the hose, flowing in a thin film all over the envelope. The 18-mile breeze caused by the travel of the airship will cause rapid evaporation, resulting in an intense cooling effect. When it is considered that the airship will have to undergo the extreme change from tropical day to night at least five to seven times, it will be evident that the conditions to be met are extremely more dangerous than those ordinarily encountered on land, where a single change from day to night in temperate zones causes most serious difficulties, so that it remains to be seen whether the results obtained with these safety devices will fulfill expectations.

Motive Power. Wellman's plan of utilizing a car and a lifeboat has been departed from by combining both in a large motor boat. This is 39 feet long by 12 feet beam and 7 feet in depth and is equipped with two 200-horse-power motors, which will not only drive the ship in the air, but the boat in the water, in case of abandonment. It is equipped with a fire- and explosion-proof gasoline tank, the efficacy of which was demonstrated in the accident to the Zeppelin VI, in which the tank remained intact though the ship was burned. The boat provides a navigating and living compartment, a complete machine shop for making repairs, a set of aeronautic and meteorologic instruments and a large store of provisions. It is suspended from the envelope in the same manner as the usual car, but between it and the envelope a light passageway is suspended, reached from the boat by a rope ladder. It gives direct access to the envelope and the valves and also provides additional "deck space." The whole equipment, however, is centered in the boat and nothing has to be transferred in an emergency as in the America.

It is hoped that the Suchard, with its speed of 18 miles an hour, plus the steady trade wind blowing 16 miles, will make 34 miles an hour, covering the distance in five days, if the machinery holds out. In case of breakdown, it will take longer, but the trade winds will insure steady progress, while there seem to be no risks that could be compared in the least with those that Wellman faced. A number of trial trips will be made before embarking on the actual enterprise with the trade wind, which allows of no return. In the light of Wellman's experience, Brucker's success would seem to depend upon his skill in handling the water-scooping and -spraying apparatus, *i. e.*, his ability in preventing the airship from rising unduly. If he succeeds in avoiding gas losses from this cause, he can hardly fail to reach the West Indies, even though the motors give out. But even a few minutes failure of these devices would suffice to send the ship to the clouds, blowing off large quantities of gas and spoiling all chances of a long voyage. The air balloonet is so large that it should compensate for considerable expansion or contraction of the gas.

Carrying Passengers by Airship. *Deutschland.* For a time, it seemed as if the year 1910 would go down in history as marking the actual inception of aerial transportation according to a regular schedule. The Deutschland (Zeppelin VII) was a true ship of the air and on a most elaborate scale. She was built for the *Deutsche Motorluftschiffahrt Gesellschaft* (German Aerial Transportation Company), incorporated to do an aerial passenger-carrying business. The airship was 490 feet long and had a capacity of 27,400 cubic yards. The budget of this aerial packet boat was as follows: The cost of the airship was to be $150,000, the gas bags to be half re-inflated every week, involving a monthly consumption of 390,000 cubic yards of hydrogen, representing an annual expenditure of $9,000; for a service of six months for fuel and lubricants $9,000 more was allowed; the crew of seven men were to receive $7,500, while $5,000 was allowed for anchorage rights; administration and unforeseen expenditures, $11,500, and a sinking fund of $75,000, bringing the total to $116,500, exclusive of the cost of the ship itself.

The passenger cabin of the Deutschland was built on an aluminum frame and lined with rosewood and mahogany, inlaid with mother-of-pearl, the walls consisting of mahogany veneer in several layers glued together, with a thickness of $\frac{1}{4}$ inch. The floor was also a mahogany veneer of the same thickness, carpeted, while the ceiling was only $\frac{1}{8}$ inch thick, veneer being employed throughout to save weight. The entire cabin was 35 feet long by 7½ feet wide and weighed only 1,600 pounds. It was divided into five compartments, each containing four cane seats, of which 1 foot only was screwed to the floor, so that the chair could be swung in all directions. Beside these five 5-foot compartments, there was an entrance vestibule and a lavatory. The window openings were remarkably wide so that an unobstructed view could be obtained in every direction. No glass was used in them, however, although in the first compartment a sliding glass window had been provided for testing purposes.

Twenty-four passengers, among them an American woman, five Germans, and three Englishmen, booked passage at the established rate of $50 a trip, for the first voyage. All told, there were thirty-three persons on board the Deutschland on her first trip. She started from Friedrichshafen at 3 A. M., traveled up the valley of the Rhine as far as Cologne and reached Düsseldorf at 3 P. M., having covered 300 miles as the crow flies. Favored by the wind the speed is said to have reached 50 miles an hour at times, the distance from Mannheim to Düsseldorf (180 miles) having been covered in four hours; an express train taking six hours, on a rather winding track. The next day, the Deutschland made a round trip from Düsseldorf to Dortmund and back, going the 37 miles out in one hour, but taking three and one-half hours for the return. As a result, voyages at frequent intervals were announced.

On June 29, 1910, the Deutschland left Düsseldorf with seventeen passengers—all newspaper men—the voyage to last four hours, but the ship was still struggling against a strong head wind five and a half hours after the start at 8:30 A. M. Then the motors began to give trouble and the fuel threatened to run short. The wind had risen to a storm and, without the aid of its motors, the ship shot up to a height of 5,000 feet, then dropped as suddenly in the forest of Teutoburg, a huge tree trunk coming up through the floor of the cabin to the dismay of the passengers. However, it broke the fall and prevented a far worse disaster, supporting the great dirigible about 40 feet from the ground. The entire after part of the ship was wrecked, the governing planes (horizontal rudders) being broken and the gas bag being torn in many places. A company of infantry dismantled the wreck, dissecting the aluminum frame, piece by piece, packing the motors and parts of the car and rolling up the fabric of the envelope, so that, in a few hours, the airship was on its way back to Friedrichshafen on the railroad instead of in the air. Lieutenant Wagner, commanding the Deutschland, attributed the accident to a combination of adverse circumstances and not to any fault of the system. The chief cause was the sudden downward whirlwind, but if the fuel had held out, the gale might have been weathered. As it was, she was at the mercy of the wind. In rising so high, a great deal of gas was lost and the wetting of the envelope in the rain caused a dangerous loss of buoyancy.

Zeppelin VI. A little less than two months later, the Zeppelin VI was also destroyed. On September 14, owing to a breakdown of one of the motors, the envelope caught fire while the crew was cleaning the machinery with gasoline from an open tank. The hydrogen in the seventeen compartments instantly ignited and the ship was completely consumed in a short time. During the fortnight preceding the fire, the Zeppelin VI had covered 2,000 miles and had carried more than 300 passengers. She was the speediest Zeppelin ever built, being credited with a speed of 38 miles an hour. On August 28, for the third time in eight days, she carried thirty passengers from Strasburg to Baden-Baden and back in three hours.

Miscellaneous Exploits. Earlier in the year, the Zeppelin II —one of the German military fleet—was also destroyed by a storm. While journeying from Hamburg to Cologne, it was necessary to anchor in an open field. On April 25, 1910, after the vessel had just received a new charge of gas, two companies of soldiers were unable to hold it down in a high wind and it was blown away. It immediately rose to a height of 700 feet and sailed away with the wind; twenty minutes later it was blown to the ground in the Lahn Valley, the bow caught in the telegraph wires and then the wind took the huge gas bag broadside and hurled it against the side of the hill at Webersburg, completely demolishing it. This accident affords a striking illustration of the chief shortcoming of the dirigible—its utter helplessness when exposed to the wind, a cause that led to the loss of La Patrie three years before, when the company of soldiers detailed for that service were unable to hold the ship and it simply blew away, never being heard of again. To be of practical use, the dirigible must be large, but its very size is its greatest element of weakness, as the cost of erecting numerous sheds to accommodate it would be prohibitive, and it can not safely anchor in the open.

In addition to the events chronicled, there were a number of successful cross-channel flights, the most striking being the round trip of the Clement-Bayard II between London and Paris, which merely afforded an excellent example of what may be done under favorable circumstances. In fact, the English Channel was crossed not less than three times in a month by airship, one of the trips being made in an English dirigible, by E. T. Willows, who had a short time prior flown from Cardiff to London. He started for Paris from London, but was compelled to descend 50 miles inland from Calais.

Despite the number of huge dirigibles that were wrecked in Germany during 1910, as well as those that came to grief in England in the following year, a great impetus has been given their building and operation for passenger service in the former country, and numerous inventors are devoting attention to the perfecting of various devices to aid in their navigation. The pilot of a huge dirigible has many things to watch, but none that requires closer attention than that of the vertical travel of the ship, to keep track of which the barographs, anemometers, and anemoscopes must be consulted continually, often to the neglect of other duties, which gives rise to dangerous situations.

Kodophone. The kodophone is an instrument specially devised for the purpose of relieving the pilot of a dirigible of the nerve-racking strain of watching a number of fine instruments to detect whether his ship is rising or falling. As its name indicates, it works on an audible rather than a visual principle. The device consists of a wind wheel located horizontally in a cylindrical metal casing and adapted to revolve easily on a vertical shaft. The metal cylinder is in turn protected by a heavy wicker basket. The wind wheel is accordingly so placed that only a vertical current of air will actuate it. A slight amount of vertical play is allowed the wheel on its vertical shaft, so that if the wind is coming from below, the wheel will rise slightly under the pressure of the wind turning it and will operate a bell above it. This would indicate that the airship was falling. With the wind coming from above, the process would be reversed and another bell of a different tone sounded. Not alone the fact that the airship is either ascending or descending, but likewise the speed and the entire period during which one or the other takes place, are directly communicated to the pilot by the bells. When both are silent, he knows with absolute certainty that the airship is traveling on a perfectly horizontal keel. This is of the greatest importance at night, when the necessarily limited amount of light on the instruments makes consulting them more than usually troublesome. It also has a further advantage in that the instruments merely show that the ship has fallen or has risen and does not reveal whether one or the other is continuing, except by close observation. To avoid disturbance due to horizontal currents being deviated into the basket by the propeller or similar means, the metal cylinder is covered at the top and bottom by fine wire gauze. It will be at once apparent that the pilot, being thus continuously informed by the bell signal, will be able without loss of time to take prompt measures for correcting any unfavorable action, saving both gas and ballast and increasing the range of the ship.

Another instrument that the aeronaut finds need of now that greater altitudes and night flights have become more common, is one that will enable him to determine his position readily. Under the circumstances, indirect methods must naturally be reverted to and several such methods have been tried in the past few years. Magnetic measurements have been employed for this purpose and successful methods of informing an aeronaut of his position by wireless telegraphy have been devised. Finally, astronomical methods have been proposed, in which the tedious reduction of the observations is effected by special apparatus. This method, of course, can be employed only at night in clear weather.

Special Aeronautical Compass. The ordinary compass is not of great value to the aeronaut or the aviator, as the direction of travel must be figured out from the indication of the compass needle, aided by the chart, all of which requires concentration that it is difficult to give when attention is required by so many other things. To overcome this, a special type of compass has been invented by an American, A. G. Marquis. It consists of a needle mounted in the usual manner, while surrounding it in the same horizontal plane is a card having the points of the compass marked on it. This chart is reversed, however, as to north and south, and the needle is so arranged that it points to the south also. The result is that the reflection in a mirror placed at an angle of 45 degrees above the chart is correct, the north point appearing at the top and the south at the bottom of the mirror. Instead of the chart moving round and the needle remaining stationary as in the ordinary compass, the needle itself apparently swings with each alteration in the course, and continuously indicates the direction in which the airship or aeroplane is traveling. The apparent movement of the pointer is the result of an optical illusion, for the needle actually remains stationary and the chart turns in the usual way. With a liquid of comparatively heavy specific gravity to deaden the vibrations of the needle, this has been found to be by far the most practical and ingenious of the many special types of compasses that have been advocated for aeronautical use. One of the best methods of overcoming vibration has been found to be the use of oil for floating the needle and a bed of springy horsehair for holding the compass case. The employment of a compass with a south-pointing needle dates back to 2600 B. C. in China, where it was used for land "navigation."

EDOUARD NIEUPORT AT THE HELM OF HIS MONOPLANE, THE SPEED AND EFFICIENCY OF WHICH ARE DUE TO THE DEEP STREAM-LINE BODY

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THEORY OF AVIATION

PART I

EARLY DAYS OF AVIATION

As the derivation of the word indicates, *aviation* is employed to refer solely to the flying machine, or the heavier-than-air type, while under the general term *aeronautics* are included balloons, dirigibles, and similar apparatus, which depend upon the use of a lighter-than-air gas to give them the necessary lifting power.

Historical. *Cayley.* Man's ideas on the subject of flight are so old as to be legendary, but going back to Icarus or before him, would not be of even academic interest in the present connection. Like that of the dirigible, the actual history of the aeroplane began about a century ago, and just as Meusnier conceived the dirigible complete, embodying in his first designs all those important principles which have since proved to be indispensable, so did Sir George Cayley achieve a startling approach in his pioneering work to what present-day success has shown to be necessary for flight. In fact, Cayley's machine represents the true prototype of the modern aeroplane, combining features of both the Wright and Bleriot forms of construction. It had a single long, narrow plane of the proportions since demonstrated to be the most effective and was designed to be "drawn" by two screws run by chains from a single motor, the propellers being placed forward and one on either side, while stability, elevation, and steering were to be obtained through the medium of a tail.

More remarkable by far, however, was the knowledge of true principles displayed by its inventor; the proper calculation of the center of thrust and the fact that displacement takes place towards the front being known to Cayley. As in the case of the dirigible, it required almost a century to "rediscover" these principles and appreciate their value as Cayley described his machine in detail in *Nicholson's Journal* in 1809. He even dwelt on the subject that is now engrossing the foremost designers and inventors, automatic stability, and described a means of obtaining it. Unlike so many early investigators, Cayley did not end with planning a machine but actually built it. This first attempt was really the original glider, as it had no motor. The results obtained with it were so promising that a second machine was constructed and equipped with a small engine designed to be run by a tank of compressed air, and the form given the latter shows that the importance of wind resistance was fully appreciated. Unfortunately, Cayley's experiments terminated with the smashing of his machine in its trials.

Henson. That the results of his investigations were not entirely lost, however, is evident from Henson's machine of 1842, which was an even more astonishing anticipation of modern invention. Henson had not alone grasped the general principles but had also anticipated the actual construction of the aeroplanes that are performing such wonders in the air today. His machine was a monoplane and the wings with their ribbing and silk covering, stayed above and below to central posts placed in the main body, is almost identical with that of the French monoplane, the auxiliary trussing at the center of the planes constituting an arrangement employed on the Antoinette. In addition to the main planes, there was a hinged rear tail, and a rudder for vertical and horizontal control, and there was likewise a three-wheel chassis on which the machine was designed to run when on the ground. As a parallel to the Wright starting rail, Henson proposed to employ an inclined plane, the run-down which would give the initial impulse necessary to launch the machine in the air.

The main planes measured 30 by 150 feet, giving an area of 4,500 square feet, designed to be covered with silk or linen and to be perfectly rigid, although an arrangement of cords was devised for "reefing" or "setting" the coverings of the wings or planes, each of the latter being divided into three independent sections for this purpose. The tail was 50 feet long and this, as well as the rudder, was controlled by cords from the car. A small, vertical plane was placed at the center of the main planes to check lateral oscillation. All of the struts and braces were designed to present the minimum resistance to the air.

A light but very strong car was built directly under the central portion of the main plane and housed the power plant which consisted of a two-cylinder, condensing steam engine, and water-tube boiler. The engine was capable of delivering about 20 horse-power and was designed to drive two six-bladed propellers, 20 feet in diameter. The condenser was practically the automobile radiator of many years later, a series of small, vertical tubes designed to be cooled by the air, so that only 20 gallons of water were necessary, and the total weight of the power plant, including its water supply, did not exceed 600 pounds. Every part of the machine was built to withstand stresses of a nature that only an expert engineer could foresee would be placed upon it. That Henson's machine would undoubtedly have met the fate that rewards every builder of an ambitious structure who has not the least idea of how to fly it, is a foregone conclusion.

Miscellaneous. This was probably responsible for the return to first principles that took place about 16 years later, when Le Bris demonstrated the first man-carrying kite in 1856. To obtain the necessary lifting force, the kite was towed by a wagon. Wenham, in 1866, made the first experiments in soaring or gliding. This was with a triplane and constituted the forerunner of the apparatus employed by Chanute, Archdeacon, and the Wrights 30 to 35 years later. Several years prior to Wenham's experiments, Nadar, D'Amecourt, and De la Handelle carried out an extended series of investigations, D'Amecourt building a working model of a steam helicopter —the first of its kind—in 1862. Enrico built another steam helicopter in 1878, weighing all told 6¾ pounds, which actually sustained itself in the air for a short time, while a year later Penaud constructed model aeroplanes on the lines of the present-day monoplane that actually soared, and Tatin's compressed-air machine suspended by a cord from a circular track showed its ability to fly independently of its support.

Langley. What may be regarded as the actual starting point of the investigation which ultimately demonstrated the possibility of human flight and the means of its attainment, dates from about 1888, when, by one of those curious coincidences which are frequently observed in the scientific world, several highly-qualified men simultaneously undertook the solution of the problem in different parts of the world. They were Professor Langley in America, Maxim in England, Lilienthal in Germany, and Hargrave in Australia. Professor Langley first began his investigation of the laws of aeroplane flight in 1887. At that time, he built the now famous "whirling table," consisting of a horizontal rotating arm at the outer end of which were carried the planes and propellers to be tested. By means of ingenious automatic recording devices, the lifting power of different forms of planes, and of the same plane at different angles of incidence, was ascertained, and in the same way the thrust of various types of propellers was recorded.

The complete results of these investigations were incorporated in a work entitled "Experiments in Aerodynamics," first published in 1891. Among the important principles established was that of the size of the supporting surface as governed by its speed of travel. That the area of the necessary supporting surface in an aeroplane varies inversely as the square of the velocity, which means that if a biplane requires 500 square feet of supporting surface at 40 miles an hour, it would need only 222 feet at 60 miles an hour, while 80 square feet would suffice for a speed of 100 miles an hour. Langley explained that this was due to the fact that at the higher speeds, the planes passed so rapidly on to new and undisturbed bodies of air, that there was not sufficient time for them to overcome the inertia of the air, an analogy to this being found in the skater on thin ice, who does not remain sufficiently long at any one point to break through. Of all the scientists who undertook the solution of the problem, Langley's work was undoubtedly the most thorough, and it is referred to more at length later, as most of his important results were achieved a few years later.

Maxim. Maxim, in 1894, undertook the construction of a huge biplane, though it bore no resemblance to any of the machines of this type of the present day. Fully $100,000 was expended on the project and the latter affords an excellent example of the wisdom of the policy adopted by the Wright Brothers at the inception of their first serious work. They realized that the most necessary thing was to learn how to fly—in other words, how to control an aeroplane before attempting to build one. Maxim was also aware of the importance of this, as evidenced by the fact that all his early experiments were made with the machine captive. It was fitted with wheels running on wood rails and supplementary guard rails were designed to prevent it from leaving the earth. The machine was so powerful, however, that it tore away from the latter and was smashed in alighting.

Some idea of the size of the Maxim machine may be conceived from its supporting area of 5,400 square feet, made up of a central rectangular plane directly over the operating platform; forward, aft, and two side planes at the same level; and two side planes at the level of the platform. This was the original design, subsequently reduced to 4,000 square feet by the elimination of the forward and side planes, a great reduction in area of the central plane and a change in its shape. to a rectangle with its long side forward, and the addition of a second smaller superimposed plane, making it practically a biplane with the machinery and operating platform suspended some distance below it. The total lift of the planes was 10,000 pounds.

The internal combustion motor not having been developed at that time, steam was employed and the power plant was of a most ingenious order, replete with novel automatic devices. The boiler was of the water-tube type, the light copper tubes being assembled in the form of a triangle, with a nest of additional tubes in serpentine form in the opening of the latter, giving a total heating surface of about 800 square feet, with a "firebox" surface of 30 square feet. Its weight with a feedwater heater and gasoline furnace was 1,200 pounds, 200 pounds of this consisting of the supply of water itself. The gasoline fuel was heated in a special receptacle and was delivered through 7,650 fine jets at a pressure of 50 pounds to the square inch. A number of ingenious devices were employed to regulate the supply of fuel as well as its pre-heating before burning. The boiler was designed to supply steam at a pressure of 360 pounds to a compound, condensing engine giving 360 horse-power.

This power drove two propellers 17 feet 10 inches in diameter by 16 feet pitch at 375 r.p.m. The screw thrust before starting reached as high as 2,100 pounds, Mr. Maxim having calculated that of the total power, 150 horse-power would be wasted in slip, 130 horse-power expended in actual lift on the angle of the planes, and 80 horse-power utilized in driving. The engine cylinders, frame, and rods were all of sheet steel so that its total weight was only 600 pounds, setting a new limit at that time of 2 pounds per horse-power. A safety device led the high-pressure steam into the low-pressure cylinders in case the boiler pressure became too high, this increasing the output to 400 horse-power. It was truly a case of Frankenstein being overpowered by the monster he himself had created, as shown by the subsequent wrecking of the machine. Even in the light of present-day knowledge, few aviators would care to attempt the handling of such a huge contrivance. When it is borne in mind that the cost of the best of modern aeroplanes does not exceed $8,000, it seems a pity that such a sum should have been expended at a time when practical results would have done so much for the development of the art.

Langley's Experiments. Two years later, or in 1896, Langley made his now historic experiments with steam-driven models, but before referring to these it will be of interest to note for how much of our present knowledge his early investigations were responsible. To give these at length from his own works would involve more space than is available, so that the following is excerpted from an address made by Prof. Alexander Graham Bell, the inventor of the telephone, on the occasion of the presentation of the Langley medal to the Wright Brothers, February 10, 1910. The indebtedness of the latter to Langley's work is fittingly acknowledged by them in their own story of their experiments, which is given on page 9.

> Langley's experiments in aerodynamics gave to physicists, perhaps for the first time, firm ground on which to stand as to the long-disputed questions of air resistance and reactions. Chanute says:
>
> (1) They established a more reliable coefficient for rectangular pressures than that of Smeaton.
>
> (2) They proved that upon inclined planes the air pressures were really normal to the surface.
>
> (3) They disproved the Newtonian law that the normal pressure varied as the square of the angle of incidence on inclined planes.
>
> (4) They showed that the empirical formula of Duchemin which had been proposed in 1836 and ignored for fifty years, was approximately correct.
>
> (5) That the position of the center of pressure varied with the angle of inclination, and that on planes its movements approximately followed the law formulated by Joessel.
>
> (6) That oblong planes, presented with their longest dimension in the direction of motion, were more effective for support than when presented with their narrower side.
>
> (7) That planes might be superposed without loss of supporting power if spaced apart certain distances which varied with the speed.
>
> (8) That thin planes consumed less power for support at high speeds than at low speeds.

The paradoxical result obtained by Langley—that it takes less power to support a plane at high speed than at low—opens up enormous possibilities for the aerodrome of the future. It results, as Chanute has pointed out, from the fact that the higher the speed, the less need be the angle of inclination to sustain a given weight, and the less, therefore, the horizontal component of the air pressure.

It is true, however, only of the plane itself, and not of the struts and frame work that go to make up the rest of the flying machine.* In order, therefore, to take full advantage of Langley's law, those portions of the machine that offer head resistance alone, without contributing anything to the support of the machine in the air, should be reduced to a minimum.

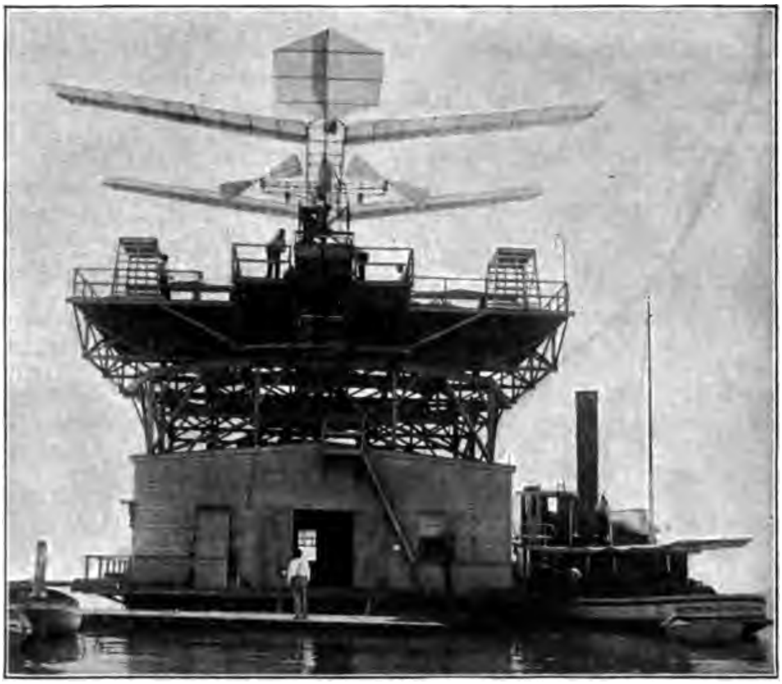

Fig. 1. Langley's Aerodrome Ready for a Flight

After laying the foundations of a science, Langley proceeded to reduce his theories to practice. Between 1891 and 1895, he built four models, one driven by carbonic-acid gas and three by steam. On May 6, 1896, his aerodrome No. 5 was tried on the Potomac River near Washington. I was a witness of this experiment, and secured photographs of the machine in the air, which have been widely published.

This aerodrome carried a steam engine and had a spread of wing of from 12 to 14 feet. It was shot into the air from the roof of a house boat anchored

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*In this is found the superiority in speed of the monoplane over the biplane.—Ed.

in a quiet bay at Quantico. It made a beautiful flight of about 3,000 feet, considerably over half a mile. It was indeed a most inspiring spectacle to see a steam engine in the air, flying like a bird. The equilibrium seemed to be perfect, though there was no man on board to control and guide the machine. I witnessed two flights of this aerodrome the same day and came to the conclusion that the possibility of flight by heavier-than-air machines had been fully demonstrated. The world took the same view and the progress of practical aerodromics was immensely stimulated by the experiments.

Langley afterward constructed a number of other aerodrome models which were flown with equal success, and he then felt that he had brought his researches to a conclusion and desired to leave to others the task of bringing the experiments to the man-carrying stage. Later, however, encouraged by the appreciation of the War Department, which recognized in the Langley aerodrome a possible new engine of war, and stimulated by an appropriation of $50,000, he constructed a full-sized machine to carry a man.

Two attempts were made, with Charles Manley as the aviator, to shoot the machine into the air from the top of a house boat, Fig. 1, but on each occasion it caught on the launching ways and was precipitated into the water. The public, not knowing the cause, received the impression that the machine itself was a failure.*

This conclusion was not warranted by the facts, and to me, and to others who examined the apparatus, it seemed to be a perfectly good flying machine, excellently constructed and the fruit of years of labor. It was simply never launched into the air, and so has never had an opportunity of showing what it could do. Who can say what a third trial might have demonstrated? The general ridicule, however, with which the first two trials were greeted, prevented any further appropriation.†

Langley's faith never wavered, but he never saw a man-carrying aerodrome in the air. He was humiliated by the ridicule which met his efforts and never recovered from his disappointment, which hastened his death. His greatest achievements in practical aerodynamics consisted in the successful construction of power-driven models which actually flew.‡ With their construction, he thought he had finished his work, and in 1901, in announcing the supposed conclusion of his labors, he said:

"I have brought to a close the portion of the work which seemed to be specially mine, the demonstration of the practicability of mechanical flight,

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*The impression was fostered by the press for the reason that Langley originally would not permit the presence of any reporters. He later consented, but the numerous delays involved in preparing the machine, together with the fact that little information was volunteered and the gentlemen in question were utterly incompetent to obtain any first hand, engendered a hostile attitude on their part. This was aggravated by tedious hours of waiting around in skiffs under the blazing sun for something in the nature of "copy" to happen, so that they were only too ready to seize upon an opportunity to ridicule. In the confusion attendant upon Manley's second spill in the water, no attention was paid to the machine at first, and it was rescued by the crew of a tugboat. Their ignorance of its construction and bungling efforts resulted in wrecking it badly, which was ascribed by the press to its fall in the water, which had in fact not damaged it particularly. Hence, the widespread report that it was an utter failure. —Ed.

†The machine has been preserved and there is a movement on foot to put it in commission and try it.—Ed.

‡These machines did not wreck themselves as had Ader's machine in France, and Maxim's in England.—Ed.

and for the next stage, which is the practical and commercial development of the idea, it is probable the world may look to others."

He was right, and the others have appeared. The aerodrome has reached the practical and commercial stage; and chief among those who are developing this field are the brothers, Orville and Wilbur Wright. They are eminently deserving of the highest honor from us for their great achievements.

Wright Brothers' Experiments. So many and varied stories have appeared of what the Wright Brothers, Fig. 2, have done and how they did it—many of them largely fiction and others so garbled as to be scarcely recognizable by those about whom they were written—that it is thought advisable to reproduce here *verbatim* their own account of their exploits, as written by them and published in the *Century*, December, 1908. This is the only true and concise report.

Fig. 2. Orville and Wilbur Wright

"Our personal interest in the subject of aerial navigation dates from our childhood days. Late in the autumn of 1878, our father came into the house one evening with some object partly concealed in his hands, and before we could see what it was, he tossed it into the air. Instead of falling to the floor, as we expected, it flew across the room until it struck the ceiling, where it fluttered awhile, and finally sank to the floor. It was a little toy, known to scientists as a helicopter, but which we, with supreme disregard for science, at once dubbed a 'bat.' It was a light frame of cork and bamboo, covered with paper, which formed two screws, driven in opposite directions by rubber bands under torsion. A toy so delicate lasted only a short time in the hands of small boys, but its memory was abiding.

"Several years later, we began building these helicopters for ourselves, making each one larger than the preceding. But, to our astonishment, we found that the larger the 'bat' the less it flew. We did not know that one machine having only twice the linear dimensions of another would require eight times the power. We finally became discouraged and returned to kite-flying, a sport to which we had devoted so much attention that we were regarded as experts. But as we became older, we had to give up this fascinating sport as unbecoming to boys of our ages.

"It was not until the sad news of the death of Lilienthal reached America, in 1896, that we again gave more than passing attention to the subject of flying. We then studied with great interest Chanute's 'Progress in Flying Machines,' Langley's 'Experiments in Aerodynamics,' the Aeronautical Annuals of 1895, 1896, and 1897, and several pamphlets published by the Smithsonian Institution, especially articles by Lilienthal and extracts from Mouillard's 'Empire of the Air.' The larger works gave us a good understanding of the nature of the problem of flying, and the difficulties in past attempts to solve it, while Mouillard and Lilienthal, the great missionaries of the flying cause, infected us with their own unquenchable enthusiasm and transformed idle curiosity into the active zeal of workers.

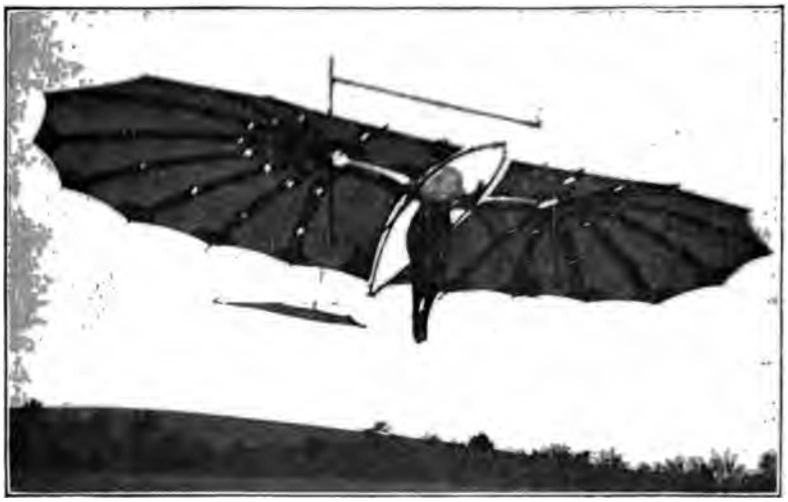

Fig. 3. Lilienthal's Gliding Apparatus

"In the field of aviation, there were two schools. The ***first,*** represented by such men as Professor Langley and Sir Hiram Maxim, gave chief attention to power flight; the *second,* represented by Lilienthal, Fig. 3, Mouillard, and Chanute, to soaring flight. Our sympathies were with the latter school, partly from impatience at the wasteful extravagance of mounting delicate and costly machinery on wings which no one knew how to manage, and partly, no doubt, from the extraordinary charm and enthusiasm with which the apostles of soaring flight set forth the beauties of sailing through the air on fixed wings, deriving the motive power from the wind itself.

Balancing Methods. "The balancing of a flyer may seem, at first thought, to be a very simple matter, yet almost every experimenter had found this to be the one point which he could not master. Many different methods were tried. Some experimenters placed the center of gravity far below the wings, in the belief that the weight would naturally seek to remain at the lowest point. It was true, that, like the pendulum, it tended to seek the lowest point; but also, like the pendulum, it tended to oscillate in a manner destructive of all stability. A more satisfactory system, especially for lateral balance, was that of arranging the wings in the shape of a broad **V** to form a dihedral angle, with the center low and the wing tips elevated. In theory, this was an automatic system, but in practice it had two serious defects: *First,* it tended to keep the machine oscillating; and *second,* its usefulness was restricted to calm air.

"In a slightly modified form, the same system was applied to the fore-and-aft balance. The main aeroplane was set at a positive angle, and a horizontal tail at a negative angle, while the center of gravity was placed far forward. As in the case of lateral control, there was a tendency to constant undulation, and the very forces which caused a restoration of balance in calms, caused a disturbance of the balance in winds. Notwithstanding the known limitations of this principle, it had been embodied in almost every prominent flying machine which had been built.

"After considering the practical effect of the dihedral principle we reached the conclusion that a flyer founded upon it might be of interest from a scientific point of view, but could be of no value in a practical way. We therefore resolved to try a fundamentally different principle. We would arrange the machine so that it would tend to right itself. We would make it as inert as possible to the effects of change of direction or speed, and thus reduce the effects of wind gusts to a minimum. We would do this in the fore-and-aft stability by giving the aeroplanes a peculiar shape; and, in the lateral balance, by arching the surfaces from tip to tip, just the reverse of what our predecessors had done. Then by some suitable contrivance actuated by the operator, forces should be brought into play to regulate the balance.

Working Its Planes. "Lilienthal and Chanute had guided and balanced their machines by shifting the weight of the operator's body. But this method seemed to us incapable of expansion to meet large conditions, because the weight to be moved and the distance of possible motion were limited, while the disturbing forces steadily increased, both with wing area and wind velocity. In order to meet the needs of large machines, we wished to employ some system whereby the operator could vary at will the inclination of the different parts of the wings, and thus obtain from the wind, forces to restore the balance, which the wind itself had disturbed. This could easily be done by using wings capable of being warped, and by supple-

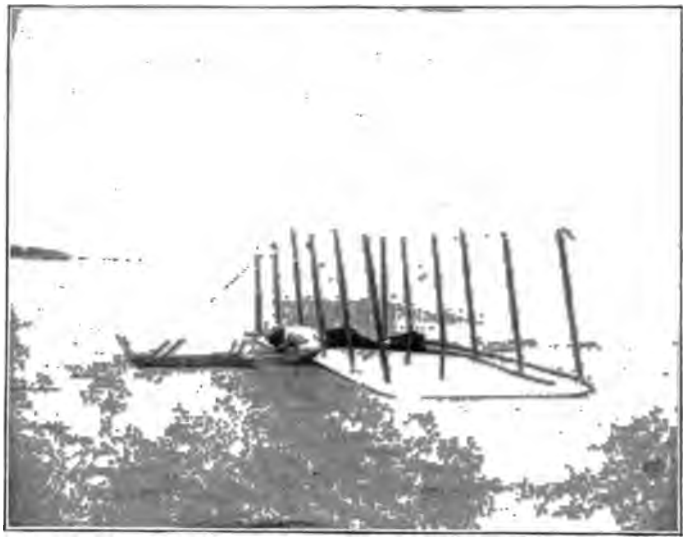

Fig. 4. An Early Wright Glider Showing Horizontal Front Rudder

mentary adjustable surfaces in the shape of rudders. As the forces obtainable for control would necessarily increase in the same ratio as the disturbing forces, the method seemed capable of expansion to an almost unlimited extent. A happy device was discovered whereby the apparently rigid system of superposed surfaces, invented by Wenham and improved by Stringfellow and Chanute, could be warped in a most unexpected way, so that the aeroplanes could be presented on the right and left sides at different angles to the wind. This, with an adjustable, horizontal front rudder, formed the main feature of our first glider, Fig. 4.

Fig. 5. Flying a Glider as a Kite to Study its Action

"The period from 1885 to 1900 was one of unexampled activity in aeronautics, and for a time there was high hope that the age of flying was at hand. But Maxim, after spending $100,000, abandoned the work; the Ader machine, built at the expense of the French government, was a failure; Lilienthal and Pilcher were killed in experiments; and Chanute and many others, from one cause or another, had relaxed their efforts, though it subsequently became known that Professor Langley was still secretly at work on a machine for the United States government. The public, discouraged by the failures and tragedies just witnessed, considered flight beyond the reach of man, and classed its adherents with the would-be inventors of perpetual motion.

"We began our active experiments at the close of this period, in October, 1900, at Kitty Hawk, North Carolina. Our machine was designed to be flown as a kite, with a man on board, in winds from 15 to 20 miles an hour. But, upon trial, it was found that much stronger winds were required to lift it. Suitable winds not being plentiful, we found it necessary, in order to test the new balancing system, to fly the machine as a kite without a man aboard, operating the levers through chords from the ground, Fig. 5. This did not give the practice anticipated but it inspired confidence in the new system of balance.

Fig. 6. Testing the Balance of a Glider with a Man Aboard

"In the summer of 1901, we became personally acquainted with Chanute. When he learned that we were interested in flying as a sport, and not with any expectation of recovering the money we were expending upon it, he gave us much encouragement. At our invitation, he spent several weeks with us at our camp at Kill Devil Hill, four miles south of Kitty Hawk, during our experiments of that and two succeeding years. He also witnessed one flight of the power-driven machine near Dayton, Ohio, in October, 1904.

"The machine of 1901 was built with the shape of surface used by Lilienthal, curved from front to rear like the segment of a parabola, with a curvature of one-twelfth the depth of its chord; to make sure that it would have sufficient lifting capacity when flown as a kite in 15- or 20-mile winds, we increased the area from 165 square feet, used in 1900, to 308 square feet—a size much larger than Lilienthal, Pilcher, or Chanute had deemed safe. Upon trial, however, the lifting capacity again fell very far short of calculation, so that the idea of securing practice while flying as a kite, had to be abandoned. Chanute, who witnessed the experiments, told us that the trouble was not due to poor construction of the machine. We saw only one other explanation—that the tables of air pressures in general use were incorrect.

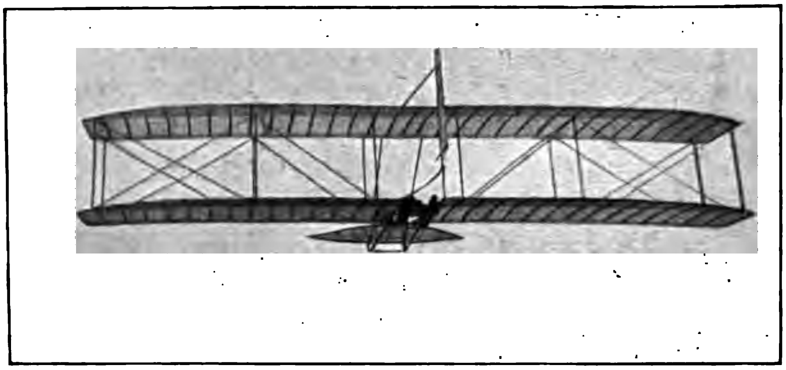

Fig. 7. Glider with Vertical Rear Rudder

Gliding Experiments. "We then turned to gliding—coasting down hill on the air—as the only method of getting the desired practice in balancing a machine, Fig. 6. After a few minutes practice we were able to make glides of over 300 feet, and in a few days were safely operating in 27-mile winds. The gliding flights were all made against the wind. The difficulty in high winds is in maintaining balance, not in traveling against the wind. In these experiments we met with several unexpected phenomena. We found that, contrary to the teachings of the books, the center of pressure on a curved surface traveled backward when the surface was inclined, at small angles, more and more edgewise to the wind. We also discovered that in free flight, when the wing on one side of the machine was presented to the wind at a greater angle than the one on the other side, the wing with the greater angle descended, and the machine turned in a direction just the reverse of what we were led to expect when flying the machine as a kite. The larger angle gave more resistance to forward motion, and reduced the speed of the wing on that side. The decrease in speed more than counterbalanced the effect of the larger angle. The addition of a fixed vertical vane, Fig. 7, in the rear increased the trouble and made the machine absolutely dangerous. It was some time before a remedy was discovered. This consisted of movable wings working in conjunction with the twisting of the wings. The details of this arrangement are given in our patent specifications, published several years ago.*

Verification of Pressure Constants. "The experiments of 1901 were far from encouraging. Although Chanute assured us that both in control and weight carried per horse-power, the results obtained were better than those of any of our predecessors, yet we saw that the calculations on which all flying machines had been based were unreliable, and that every experimenter was simply groping in the dark. Having set out with absolute faith in the existing scientific data, we were driven to doubt one thing after another, till finally, after two years of experiment, we cast it all aside and decided to rely entirely upon our own investigations. Truth and error were everywhere so intimately mixed as to be indistinguishable. Nevertheless, the time expended in the preliminary study of books was not misspent, for they gave us a good general understanding of the subject and enabled us at the outset to avoid effort in many directions in which results would have been hopeless.

"The standard for measurements of wind pressures is the force produced by a current of air of 1-mile-per-hour velocity striking against a plane of 1 square foot area. The practical difficulty of obtaining an exact measurement of this force has been great. The measurements by different recognized authorities vary 50 per cent. When this simplest of measurements presents so great difficulties, what shall be said of the troubles encountered by those who attempt to find the pressure at each angle as the plane is inclined more and more edgewise to the wind? In the eighteenth century, the French Academy prepared tables giving such information, and at a later date the Aeronautical Society of Great Britain made similar experiments.

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*See pages 65 and 75, Aeronautical Practice, Part II.

Many persons likewise, published measurements and formulas; but the results were so discordant that Professor Langley undertook a new series of measurements, the results of which form the basis of his celebrated work 'Experiments in Aerodynamics.' Yet a critical examination of the data upon which he based his conclusions as to pressures at small angles shows results so various as to make many of his conclusions little better than guesswork.

"To work intelligently, one needs to know the effects of a multitude of variations that could be incorporated in the surfaces of flying machines. The pressures on squares are different from those on rectangles, circles, triangles, or ellipses; arched surfaces differ from planes, and vary among themselves according to the depth of curvature; true arcs differ from parabolas, and the latter differ among themselves; thick surfaces differ from thin, and surfaces thicker in one place than another vary in pressure when the positions of maximum thickness are different; some surfaces are most efficient at one angle, others at other angles. The shape of the edge also makes a difference, so that thousands of combinations are possible in so simple a thing as a wing.

"We had taken up aeronautics merely as a sport. We reluctantly entered on the scientific side of it. But we soon found the work so fascinating that we were drawn into it deeper and deeper. Two testing machines were built, which we believed would avoid the errors to which the measurements of others had been subject. After making preliminary measurements on a great number of surfaces to secure a general understanding of the subject, we began systematic measurements of standard surfaces so varied in design as to bring out the underlying causes of differences noted in their pressures. Measurements were tabulated on nearly fifty of these at all angles from zero to 45 degrees, at intervals of 2½ degrees. Measurements were also secured showing the effects on each other when surfaces are superposed, or when they follow one another.

"Some strange results were obtained. One surface, with a heavy roll at the front edge, showed the same lift for al angles from 7½ to 45 degrees. A square plane, contrary to the measurements of all our predecessors, gave a greater pressure at 30 degrees than at 45 degrees. This seemed so anomalous that we were almost ready to doubt our own measurements when a simple test was suggested. A weather vane with two planes attached to the pointer at an angle of 80 degrees with each other was made. According to our tables, such a vane would be in unstable equilibrium when pointing directly into the wind; for if, by chance, the wind should happen to strike one plane at 39 degrees and the other at 41 degrees, the plane with the smaller angle would have the greater pressure, and the pointer would be turned still further out of the course of the wind until the two vanes again secured equal pressures, which would be approximately at 30 and 50 degrees. But the vane performed in this very manner. Further corroboration of the tables was obtained in the experiments with a new glider at Kill Devil Hill the next season.

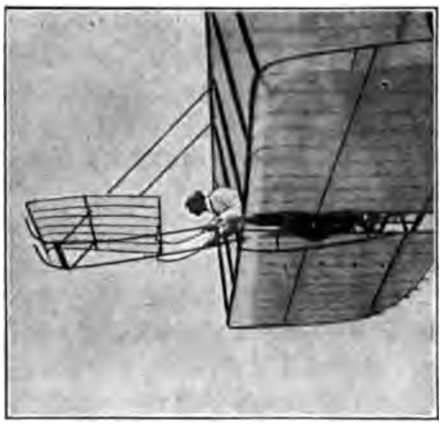

Fig. 8. Gliding Flight, Showing Prone Position of Operator

"In September and October, 1902, nearly 1,000 gliding flights were made, several of which covered distances of over 600 feet (all made with the operator lying prone as shown in Fig. 8). Some glides against a wind of 36 miles an hour gave proof of the effectiveness of the devices for control. With this machine, in the autumn of 1903, we made a number of flights in which we remained in the air for over a minute, often soaring for a considerable time in one spot without any descent at all. Little wonder that our unscientific assistant should think the only thing needed to keep it in the air indefinitely would be a coat of feathers to make it light!

"With accurate data for making calculations, and a system of balance effective in winds as well as in calms, we were now in a position, we thought, to build a successful power flyer. The first designs provided for a total weight of 600 pounds, including the operator and an 8-horse-power motor. But upon completion, the motor gave more power than had been estimated, and this allowed 150 pounds for strengthening the wings and other parts.

Propeller Design. "Our tables made the designing of the wings an easy matter; and as screw propellers are merely wings traveling in a spiral course, we anticipated no trouble from this source. We had thought of getting the theory of the screw propeller from the marine engineers, and then, by applying our tables of air pressures to their formulas, of designing air propellers. But so far as we could learn, the marine engineers possessed only empirical formulas, and the exact action of the screw propeller, after a century of use, was still very obscure. As we were not in a position to undertake a long series of practical experiments to discover a propeller suitable for our machine, it seemed necessary to obtain such a thorough understanding of the theory of its reactions as would enable us to design them from calculation alone. What at first seemed a simple problem, became more complex the longer we studied it. With the machine moving forward, the air flying backward, the propellers turning sidewise, and nothing standing still, it seemed impossible to find a starting point from which to trace the various simultaneous reactions. Contemplation of it was confusing. After long arguments, we often found ourselves in the ludicrous position of each having been converted to the other's side, with no more agreement than when the discussion began.

"It was not until several months had passed, and every phase of the problem had been threshed over and over, that the various reactions began to untangle themselves. When once a clear understanding had been obtained there was no difficulty in designing suitable propellers, with proper diameter, pitch, and area of blade, to meet the requirements of the flyer. High efficiency in a propeller is not dependent upon any particular or peculiar shape, and there is no such thing as a *best* screw. A propeller giving a high dynamic efficiency when used upon one machine, may be almost worthless when used upon another. The propeller should in every case be designed to meet the particular conditions of the machine to which it is to be applied. Our first propellers, built entirely from calculation, gave in useful work 66 per cent of the power expended. This was about one-third more than had been secured by Maxim or Langley.

First Power Flight. "The first flights with the power machine were made on the 17th of December, 1903. Only five persons beside ourselves were present. These were Messrs. John T. Daniels, W. S.

Dough, and A. D. Etheridge of the Kill Devil life saving station; W. C. Brinkley of Manteo; and John Ward of Naghead. Although a general invitation had been extended to the people living within 5 or 6 miles, not many were willing to face the rigors of a cold December wind in order to see, as they no doubt thought, another flying machine *not fly*. The *first* flight lasted only 12 seconds, a flight very modest compared with that of birds, but it was, nevertheless, the first in the history of the world in which a machine carrying a man had raised itself by its own power into the air in free flight, had sailed forward on a level course without reduction in speed, and had finally landed without being wrecked. The *second* and *third* flights were a little longer, and the *fourth* lasted 59 seconds, covering a distance of 853 feet over the ground against a 20-mile wind, Fig. 9.

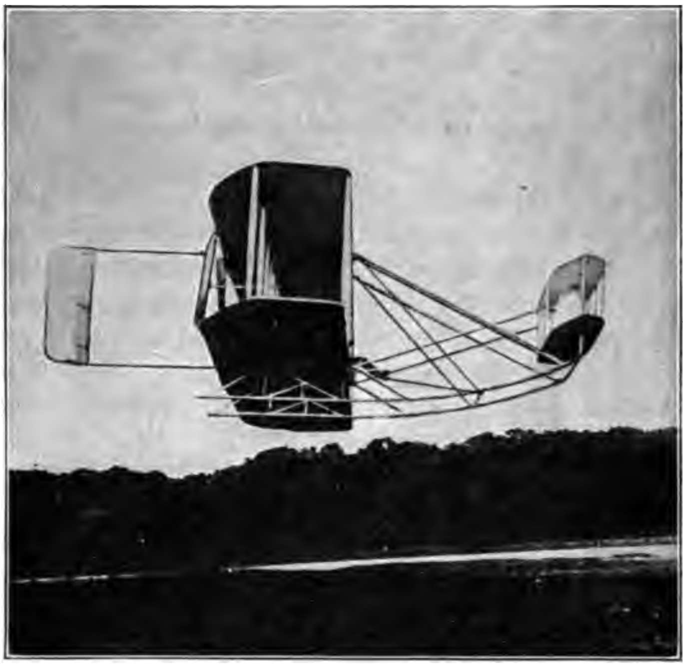

Fig. 9. One of the First Power Flights of the Wright Biplane

"After the last flight, the machine was carried back to camp and set down in what was thought to be a safe place. But a few minutes later, while we were engaged in conversation about the flights, a sudden gust of wind struck the machine and started to turn it over. All made a rush to stop it but we were too late. Daniels, a giant in stature and strength, was lifted off his feet and, falling inside between the surfaces, was shaken about like a rattle in a box while the machine rolled over and over. He finally fell out upon the sand with nothing worse than painful bruises, but the damage to the machine caused a discontinuancce of the experiments.

"In the spring of 1904, through the kindness of Torrence Huffman of Dayton, Ohio, we were permitted to erect a shed and continue experiments, on what is known as the Huffman prairie, at Simms Station, eight miles from Dayton. The new machine was heavier and stronger but similar to the one flown at Kill Devil Hill. When it was ready for its first trial, every newspaper in Dayton was notified, and about a dozen representatives of the press were present. Our only request was that no pictures be taken and that the reports be unsensational, so as not to attract crowds to our experiment grounds. There were probably 40 persons altogether on the ground. When preparations were completed, a wind of only 3 or 4 miles an hour was blowing—insufficient for starting on so short a track—but since so many had come a long way to see the machine in action, an attempt was made. To add to the other difficulty, the engine refused to work properly. The machine, after running the length of the track, slid off without rising into the air at all. Several of the newspaper men returned the next day but were again disappointed. The engine again performed badly and after a glide of only 60 feet, the machine came to the ground. Further trial was postponed until the engine could be put in better condition. The reporters had now, no doubt, lost confidence in the machine, though their reports, in kindness, concealed it. Later, when they heard that we were making flights of several minutes' duration, knowing that longer flights had been made in airships, and not knowing any essential difference between airships and flying machines, they were but little interested.

"We had not been flying long in 1904 before we found that the problem of equilibrium had not as yet been entirely solved. Sometimes, in making a circle, the machine would turn over edgewise in spite of anything the operator could do, although, under the same conditions in ordinary straight flight, it could have been righted in an instant. In one flight, in 1905, while circling around a honey locust tree at a height of about 50 feet, the machine suddenly began to turn up on one wing and took a course toward the tree. The operator, not relishing the idea of landing in a thorn tree, attempted to reach the ground. The left wing, however, struck the tree at a height of 10 or 12 feet from the ground and carried away several branches; but the flight, which had already covered a distance of 6 miles, was continued to the starting point.

"The causes of these troubles, too technical for explanation here, were not entirely overcome till the end of September, 1905. The flights then rapidly increased in length, till experiments were discontinued, after the 5th of October, on account of the number of people attracted to the field. Although made on a ground open on every side, and bordered on two sides by much traveled thoroughfares, with electric cars passing every hour, and seen by all people living in the neighborhood for miles around, and by several hundred others, yet these flights have been made by some newspapers the subject of a great 'mystery.'

Fig. 10. Preparing the Machine for the Start

"A practical design having been finally realized, we spent the years 1906 and 1907 in constructing new machines and in business negotiations. It was not until May of this year (1908) that experiments (discontinued in October, 1905) were resumed at Kill Devil

Hill, North Carolina. The recent flights were made to test the ability of our machine to meet the requirements of a contract with the United States government to furnish a flyer capable of carrying two men and sufficient fuel and supplies for a flight of 125 miles, with a speed of 40 miles an hour. The machine used in these tests was the same one with which the flights were made at Simms Station in 1905, though several changes had been made to meet present requirements. The operator assumed a sitting position, instead of lying prone as in 1905, and a seat was added for a passenger. A larger motor was installed, and radiators and gasoline reservoirs of larger capacity replaced those previously used. No attempt was made to make high or long flights.

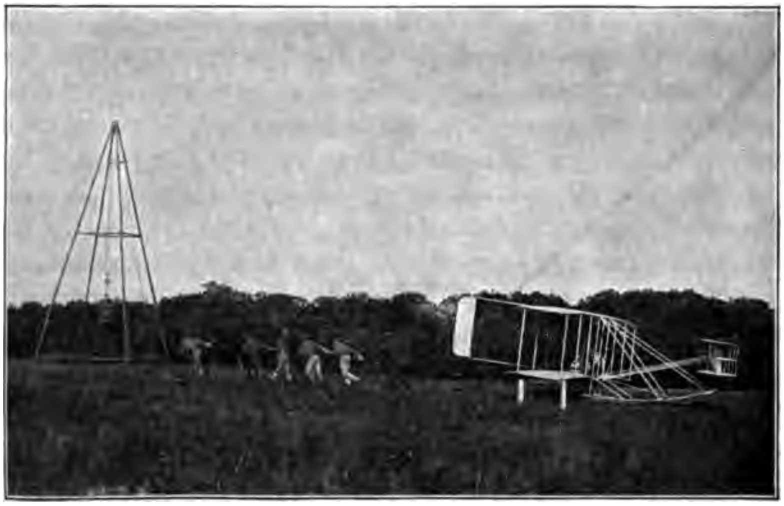

Fig. 11. Starting Device Used with the Early Wright Machines

Management of an Aeroplane. "In order to show the general reader the way in which the machine operates, let us fancy ourselves ready for the start, Fig. 10. The machine is placed upon a single rail track facing the wind and is securely fastened with a cable, Fig. 11.* The engine is put in motion and the propellers in the rear whir. You take your seat at the center of the machine beside the operator. He slips the cable and you shoot forward. An assistant,

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*Now obsolete through adoption of wheeled chassis.—Ed.

who has been holding the machine in balance on the rail, starts forward with you but before you have gone 50 feet the speed is too great for him, and he lets go. Before reaching the end of the track, the operator moves the front rudder and the machine lifts from the rail like a kite supported by the pressure of the air underneath it. The ground under you at first is a perfect blur, but as you rise objects become clearer. At a height of 100 feet you feel hardly any motion at all, except for the wind which strikes your face. If you did not take the precaution to fasten your hat, you have probably lost it by this time. The operator moves a lever; the right wing rises, and the machine swings about to the left. You make a very short turn, yet do not feel the sensation of being thrown from your seat, so often experienced in automobile and railway travel. You find yourself facing toward the point from which you started. The objects on the ground now seem to be moving at a much higher speed, though you perceive no change in the pressure of the wind on your face. You know then that you are traveling with the wind. When you near the starting point, the operator stops the motor while still high in the air. The machine coasts down at an oblique angle to the ground, and, after sliding 50 to 100 feet, comes to rest. Although the machine often lands when traveling at a speed of a mile a minute you feel no shock whatever, and can not, in fact, tell the exact moment at which it first touched the ground. The motor beside you kept up an almost deafening roar during the whole flight, yet in your excitement you did not notice it until it stopped.

"Our experiments have been conducted entirely at our expense. In the beginning, we had no thought of recovering what we were expending, which was not great and was limited to what we could afford for recreation. Later when a successful flight had been made with a motor, we gave up the business in which we were engaged, to devote our entire time and capital to the development of a machine for practical uses. As soon as our condition is such that constant attention is not required, we expect to prepare for publication the results of our laboratory experiments, which alone made an early solution of the flying problem possible."

United States Government Requirements. The War Department had called for bids on heavier-than-air flying machines, and three aeroplanes were accepted for trial. The Wright machine was one of these, and the others were submitted, one by A. M. Herring, and the other by James F. Scott. The official tests took place during the early part of September, 1908, at Fort Meyer, Virginia, across the Potomac from Washington. The Wright flyer was the only one of this type of flying machine to take part, although the Baldwin dirigible fulfilled the conditions required of it and was accepted, as has been mentioned before.

The conditions imposed by the War Department were generally believed by experts to be impossible of fulfillment. It was demanded that the machine should make an endurance flight of one hour; that it should have a speed of 40 miles an hour in still air; that it should be able to carry sufficient fuel for a flight of 125 miles; and that it should be capable of carrying two persons with a combined weight of 360 pounds. Three tests for speed and three for endurance were to be allowed.

It was required that during the endurance flight the aeroplane should remain continuously in the air for one hour, that it should be under perfect control, and that it should return to the starting point and alight without mishap. Further, it was demanded that the machine should be so designed as to be assembled and ready for operation within 60 minutes—the apparatus being of such construction as to be readily taken apart, transported in a couple of wagons, and put together again whenever wanted for service.

If these conditions were met, the government, it was understood, would pay $25,000 for the machine. They certainly seemed next to impossible, and nobody—least of all the army officers appointed to supervise the trial—imagined that they could be fulfilled. Only the Wrights themselves were confident. The machine offered for test was a new machine, never flown, and its construction embraced some novel features, the most important being a modification which enabled the aviator to sit erect.

Tests of 1908. On September 9, Orville Wright made a continuous flight of 36 miles, staying in the air 57 minutes and 31 seconds. That evening, he made another flight of 38½ miles in 1 hour, 2 minutes, and 15 seconds. This not only broke all records but was a flight of over twice the duration of any previously made. He then took Lieutenant Lahm of the United States Army as a passenger for a short trip.

Three days later he stayed in the air 1 hour and 14 minutes, making a speed of nearly 29 miles per hour. No attempts at great altitudes were made, 250 feet being about the greatest height attained.

A deplorable accident occurred on September 17, which showed that the flyer was not yet proof against mechanical defects. On this trip, Orville Wright took Lieutenant Selfridge with him as passenger. When they were preparing to descend, after a very successful flight, one of the propellers caught in a stay wire and snapped. The machine fell to the ground, pinning the aviators under it. Lieutenant Selfridge was killed, and Wright received rather severe, but temporary, injuries. This accident prevented the completion of the government tests.

Wilbur Wright in Europe. *In France.* Meantime, Wilbur Wright, in France, was preparing to give demonstrations of his machine with a view to selling his French patents. At first he was not regarded very seriously in that country, and the French comic papers hailed him as *"le Bluffeur."* They quickly acknowledged their mistake when, on September 21, he made a continuous flight of over an hour and a half at Le Mans.

World's Record Broken. On the last day of the year 1908, Wilbur Wright won the Michelin prize and $4,000 in cash, and made a new world's flying record of 2 hours, 18 minutes, and 33 seconds; official distance covered, 77 miles and 760 yards; actual distance, making allowance for the distance lost in turns, about 95 miles—the longest flight ever made by a heavier-than-air machine. Because of his success in France, Wilbur Wright sold his French patents to the Astra Company.

Flights in Italy. During March and April, 1909, Wright made some successful flights in Italy for the War Department. He taught some of the Italian officers the art, but his pupils still had something to learn, as one of them had an accident due to faulty steering. Wilbur Wright sold his Italian rights to a syndicate which is manufacturing his machines for military and other purposes.

United States Government Requirements Fulfilled. In the latter part of June, 1909, Orville Wright, assisted by his brother, again attempted to fulfill the conditions imposed by the United States War Department. The trials were made at Fort Meyer, Virginia, as were those of the year before. A new motor was used and his early attempts were unsuccessful, because the engine had not been thoroughly tested.

In later attempts the machine failed to rise properly, and the inventors turned their attention to the starting power. They added about sixty pounds to the weight which gives the initial momentum, dug a deep pit to give the weight a longer fall, and lengthened the starting rail by about 12 feet. This seemed to remedy the trouble, for no further difficulty was encountered. On July 20, a new American record was established, Orville Wright remaining in the air over 1 hour and 20 minutes.

The first part of the government requirements were met a week later, when Orville Wright made a flight of nearly an hour and a quarter—carrying a passenger—at a speed averaging about 40 miles per hour. Incidentally, this broke his brother's best record for a flight with passenger made in France the year before.

On July 30, Orville Wright met the last test of his aeroplane at Fort Meyer; and for the first time in its history the government became possessor of a flying machine. On a straightaway course of 5 miles out and return, with a passenger, Lieut. Benjamin D. Foulois, Wright maintained a speed of something over 42 miles an hour, and won for himself and brother, in addition to the $25,000 contract price of the machine, a bonus of more than $5,000. The elapsed time of the flight, according to the official figures, was 14 minutes and 42 seconds.

The conditions of the speed test were as simple as they were severe. The aeroplane was required to fly 5 miles straightaway from the Fort Meyer parade grounds to and around an army balloon anchored at the end of the course and back to the starting point. For every mile of speed less than 40 miles an hour, a penalty of 10 per cent on the contract price of the aeroplane was to be deducted from that price, and for every mile in excess of 40 miles an hour attained during the flight, a bonus of 10 per cent was to be added. A speed of less than 36 miles an hour meant the rejection of the machine.

The course was over an exceedingly rough and dangerous country, so far as affording safe landing places for a flying machine was concerned, as it was made up of hills, valleys, and thick woods for almost the entire distance. In addition to the landing difficulties the many air currents made this particularly treacherous territory.

The 5-mile limit was marked by a small army balloon anchored on Shuter's Hill, 2 miles back of Alexandria. Another balloon at Four Mile Run marked the middle of the course and served as a guide to the aeronauts. A field telephone was established between Shuter's Hill and the starting line.

Orville Wright established a new world record for aeroplanes in cross-country flying. No aeroplane had ever before flown across a country as rough and broken as lay under this course, and never before had a flight of equal distance been attempted by any aeroplane carrying two persons. Other cross-country flights had been made in France, but the conditions were more favorable.

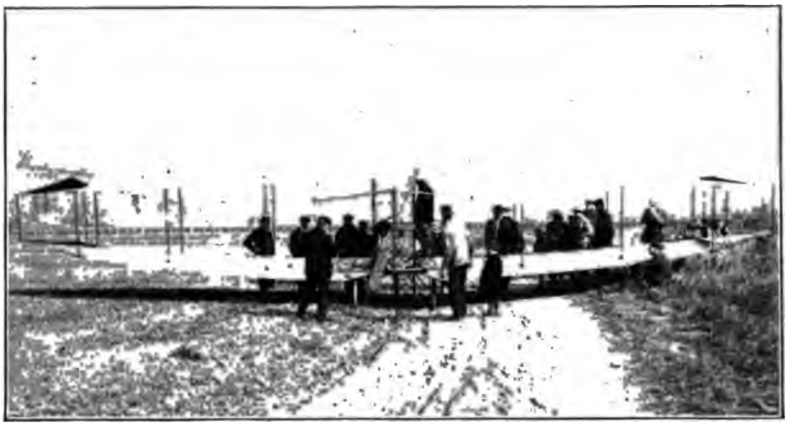

Fig. 12. Silver Dart, a Successful Model of the Aerial Experiment Association

Aerial Experiment Association. An organization which has accomplished a great deal that is of experimental value during its short life, was the Aerial Experiment Association at Hammondsport, New York. This was composed of such enthusiasts as Dr. Alexander Graham Bell, Glenn H. Curtiss, Lieutenant Selfridge (who met his death in the accident at Fort Meyer), and others. The association was organized in 1907 and lasted till 1909. Aside from the tests of Dr. Bell's tetrahedral kites, a most successful type of aeroplane was developed, the Silver Dart, illustrated in Fig. 12, being one of the several machines produced.

There are two distinctive features in the design. The first is the general principle and arrangement of the truss which supports the two surfaces, being a double bowstring truss, which was found to have structural advantages over the flat-bridge design commonly used. The other features which distinguish the machine from the usual type of double-deck machines lie in the shape of the supporting surfaces, which are very much like a bird's wing in plan, tapering toward the tips, and at the same time decreasing in curvature.

Red Wing. The Association's first aeroplane, the Red Wing, flew 318 feet above Lake Keuka on March 12, 1908. It has almost the same construction as the White Wing (which will be described in detail), except that it was mounted on runners. On its first flight the tail of the Red Wing buckled. This was a horizontal single-surface tail, and was then changed to a two-surface box shape much like that used on the Farman aeroplanes. In a flight a few days later, the aeroplane tipped and fell on the ice and was completely demolished.

Fig. 13. June Bug, an A. E. A. Machine

White Wing. The next machine, the White Wing, was mounted on bicycle wheels. A wood propeller was used with an eight-cylinder, 40-horse-power, air-cooled Curtiss gasoline engine. The diameter of the propeller was a little over 6 feet. The aeroplane was 42 feet 6 inches long from tip to tip, and 4 feet deep at the outside panel. It had a total supporting area of 408 square feet, and weighed 430 pounds. A box-shaped tail like that used last on the Red Wing was mounted in the rear, and in the middle was a vertical rudder. A double-surface horizontal rudder was placed in front. The wing tips were pivoted at their forward edges and made to move up and down slightly by means of a cord attached to the aviator's body. It was thought that the instinctive leaning of the aviator to one side in making turns could be made to set the wings properly.

Fig. 14. View of Power Plant of Silver Dart, J. A. D. McCurdy at the Wheel

On one attempt, the White Wing covered over 1,000 feet. It was driven by G. H. Curtiss, and was his first flight. The machine touched earth once after covering about 600 feet, but at once rose and continued for another 400 feet.

June Bug. The next machine was the June Bug, shown in Fig. 13. In its construction, the June Bug had the two main superposed surfaces, with a spread of 42 feet 6 inches, including wing tips, and with a total supporting surface of 370 square feet. The motor was of 25 horse-power, with 8 cylinders, and a speed of 1,000 revolutions per minute. The total weight of the machine with motor was 650 pounds.

Silver Dart. The June Bug was superseded by the Silver Dart built under the direction of J. A. D. McCurdy, of the Aerial Experiment Association, who is seen at the wheel in Fig. 14. It made its first successful flight at the grounds of the Association at Stony Brook Farm on December 15, 1908. There were several trials, all of which proved satisfactory.

In the Silver Dart, the propeller was placed differently than in earlier machines. Not only was a forward motion for the whole machine obtained by the new arrangement, but a buoyant or lifting effect was also produced. The engine was of a similar design to the June Bug, but of twice the horse-power. An excellent view of the installation of the engine and propeller is given in Fig. 14. The total weight of the Silver Dart, including its burden, a man weighing, say 150 pounds, was 860 pounds.

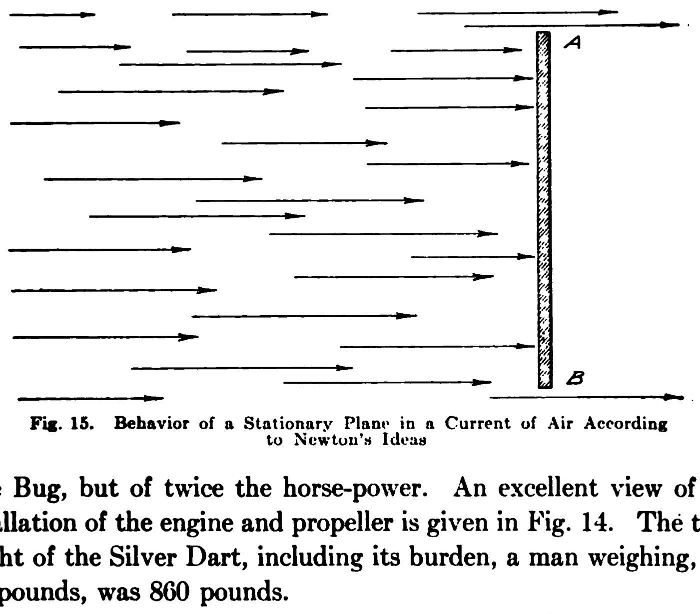

Fig. 15. Behavior of a Stationary Plane in a Current of Air According to Newton's Ideas

Herring-Curtiss Company. The success attained by the machines of the Aerial Experiment Association, and especially the Silver Dart, was attracting wide-spread attention in Europe, and it was feared that, as in the case of the Wright Brothers, the benefits of these inventions would go to Europe. To prevent this, Courtland Field Bishop, president of the Aero Club of America, formed a company, in which the interests of Glenn H. Curtiss and A. M. Herring were combined. Curtiss' motorcycle and aeronautic motor factory was taken over by this company, and afforded an excellent base for beginning operations. Herring claims to own basic patents on the only solution of anything approaching automatic control of aeroplanes so far proven practicable. With the organization of the Herring-Curtiss Company came the dissolution of the Aerial Experiment Association.

ELEMENTARY AERODYNAMICS

Air Resistance. While an extended study of the theoretical side of flight would involve going deeply into mathematics and would in itself require a volume for its exposition, it is essential for the student to know at least the principles upon which flight is based; especially as applied to the design of the successful aeroplanes. The most important single factor is the resistance of the air, and a knowledge of its bearing upon aviation, particularly in the consideration of the pressure on the surface of an aeroplane, is fundamental. Although it has been the subject of study for centuries, it has been only within comparatively recent times that either the true nature of the atmosphere, or reliable data concerning its action, has been formulated. For instance, Sir Isaac Newton, in his "Principia," defines air as an "elastic, non-continued, rare medium consisting of equal particles freely disposed at equal distances from each other." In accordance with this, if *AB*, Fig. 15, is a section of a surface against which a stream of air is blowing, all the particles of air strike directly against the surface, as indicated by the arrows. In contrast with this, Newton defined water, oil, etc., as "continued mediums," in which all the particles generating the resistance do not come in immediate contact with the surface. The latter is pressed upon only by the particles that lie next to it; these in turn being pressed by those beyond, and so on. The character of this fluid pressure is shown by Fig. 16, and subsequent investigators in demonstrating the fallacy of Newton's theory, show that air, as a medium, is similar in character to water, so that Fig. 16

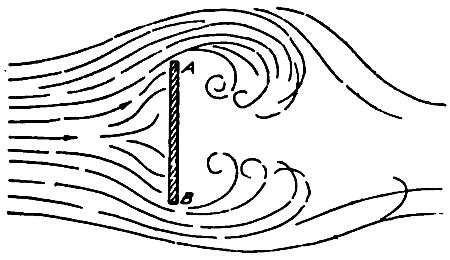

Fig. 16. Correct Idea of Air Currents Set Up by a Plane

also illustrates the action of a stream of air in striking a flat surface held at right angles to its course.

Newton calculated that the resistance of a "continued medium" varies in the "duplicate ratio of the velocity," and directly as the density of the medium itself. Robins, in 1746, with a view to determining the resistance of the air to cannon balls, whirled planes and spheres about a circular orbit, and found that the resistance varied directly as the square of the velocity. This was also determined to be true in various ways by later experimenters, Rennie having so abundantly verified this relation for low velocities in 1830, that it has since been accepted without question.

Constant K of Air Resistance. But to accurately calculate the pressure on a given surface, we must have another factor and that is the density of the medium pressing against the surface. There is a great deal of variance between different investigators regarding the value of this factor, but once it is known, the resistance of the air may be expressed in terms of pounds pressure by the following formula:

Pressure equals constant × area × velocity squared

or

$$P = KAV^2$$

where K is the "constant of air resistance," the value of which depends upon the density (barometric pressure) and temperature of the air and the character of the surface of the plane. This equation may be derived from the laws of mechanics as follows:

Let W equal the weight of the air directed against any normal surface in a given time; w equal weight in pounds of one cubic foot of air; V equal velocity of the air stream in feet per second; A equal area of surface on which pressure acts; M equal mass of air of weight W; g equal acceleration due to gravity, or 32.2 feet per second; and P equal pressure on the area A. Then the total weight W will equal the product of the weight of the total number of cubic feet w, times the area, times the velocity, or

$$W = wAV$$

But the momentum of the force on the area is equivalent to the mass times its velocity; and if A be assumed to equal one square foot, w equals 0.0807 pounds, or the weight of air per cubic foot at

32°F. and 30 inches barometric pressure, and V may be expressed in miles per hour. Then, since $VP = MV$,

$$P = .0054\ V^2$$

K thus taking the theoretical value .0054 where V is expressed in miles per hour and P in pounds per square foot.

In 1759, Smeaton deduced the formula $P = .005\ V^2$, and considering A as unity, he published a table of velocity and pressure of the wind. His actual value for K was .00492, but it early became customary in engineering practice to take it as .005. This table was regarded as a standard in engineering textbooks for years, but as long since it has been shown to be erroneous, it is not given here.

Numerous other investigators have deduced the value of K as ranging all the way from .0025 to .0055. In 1842 Colonel Duchemin derived it as .00492 and published the results of a thorough series of experiments which have proved very valuable. Early investigators erred, however, in the method of making their experiments which were conducted with the aid of a revolving member or "whirling table," and overlooked the disturbing effects of the cyclonic action thus set up. The values deduced by more recent experimenters employing surfaces either held rigid against the stream of air, or moved directly into it, are as follows:

Col. Renard	1887	$K = .00348$
Langley	1888	$K = .00389$ to .00320
Lilienthal	1889	$K = .005$
Voisin	1900	$K = .0025$
Wright Brothers	1901	$K = .0033$
Eiffel	1903	$K = .0031$

Eiffel was among the first to recognize two sources of inaccuracy —the neglect of the consideration of separate air filaments which vary at different points on the surface, and the cyclonic action of the air due to a revolving source. His experiments were carried out on the Eiffel Tower. The surface was attached to a carriage by springs, the pressure being recorded on a blackened cylinder. The carriage was allowed to fall vertically about 312 feet and was constrained in its motion by a vertical cable.

The coefficient K varied remarkably little and was practically determined as .0031. He also found, that between 700 and 1,300 feet per second the pressure was proportional to the square of the velocity, but that at about 1,300 feet per second, it began to increase and vary as the cube. As it is unlikely that aeroplanes will ever reach such velocities, this is a factor that need not be considered.

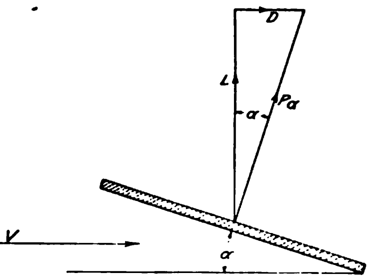

Fig. 17. Diagram Showing Lift and Drift of a Plane

Out of the great number of experiments of this kind, conducted in various ways, those carried out on the Berlin-Zossen electric line in 1903 are undoubtedly the most accurate as well as the best applicable to the actual conditions of a large body moving through the air at high speed. Velocities as high as 120 miles an hour were attained and the air resistance carefully measured by an elaborate set of pressure gauges. The mean value of the results as plotted on a chart gave $P = .0027\ V^2$.

Comparing the result of grouping the values as determined in three different ways and taking their average, we have

(1) $K = .0054$ (by theory)
(2) $K = .0042$ (by rotating apparatus)
(3) $K = .0029$ (by movement in a straight line)

For the purpose of calculations of pressures on an aeroplane, the third is naturally the most accurate, so that for figuring air pressures as applied to aeroplanes, the most practical expression of such pressure is $P = .003\ AV^2$, where $K = .003$.

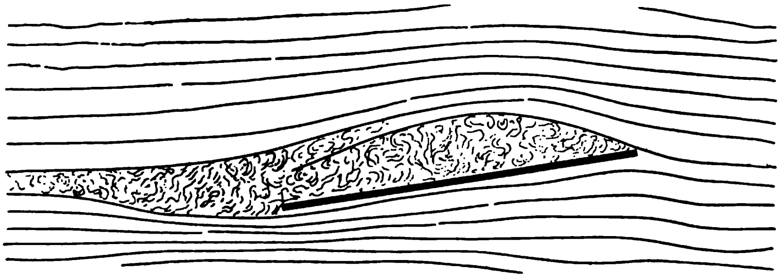

Fig. 18. Disturbances Caused in Air by a Plane at a Small Angle of Incidence

Air Pressure on Moving Surfaces. *Plane Surfaces.* This is the starting point in all aeroplane calculations. Next comes the action of different forms of surfaces when moved forward through the air. Investigations of this phase of the subject also date back to Newton, but a great deal of the work of early experimenters was shown to be wrong by Langley, who verified Duchemin's neglected formula of 1842.

Assuming P_a to represent the pressure acting perpendicularly to the surface of a plane inclined at an angle in a wind current of velocity V, we may resolve it into two components at right angles; one acting perpendicularly and equal to L, and another acting horizontally and equal to D, Fig. 17. In the present terminology of aerodynamics, L is termed the *lift* and D the *drift* of a plane. Then

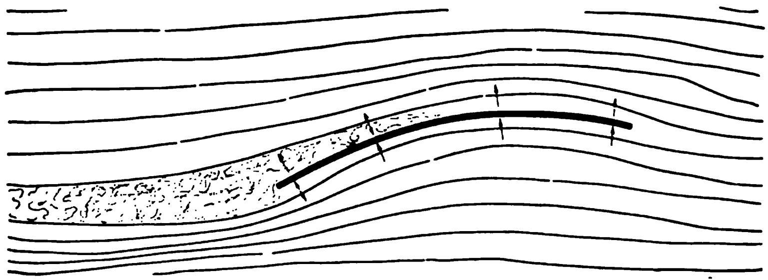

Fig. 19. Disturbances Caused in Air by a Curved Plane at a Small Angle of Incidence

$$D = P_a \sin \alpha$$

and

$$L = P_a \cos \alpha$$

This was resolved as early as 1809 by Sir George Cayley and has since been verified by Langley and by actual practice. The ratio of these two quantities LD, termed the *ratio of lift to drift*, is the means of expressing the aerodynamic efficiency of the supporting surface of an aeroplane.

Curved Surfaces. Up to Lilienthal's time all experiments had been made with flat surfaces and as the result of his study of birds' wings, he was the first to recognize that even very slight curvatures of the plane profile (section) considerably increased the lifting power. The reactions and disturbances of flat and curved planes traveling through the air are graphically illustrated by Figs. 18 and 19. In a flat plane, the pressure is always perpendicular to the surface and, as already pointed out, the ratio of lift to drift is, therefore, as the cosine to the sine of the angle of incidence. The angle of incidence is the angle at which the plane is inclined to the air current. But in curved surfaces, Fig. 20, as first shown by Lilienthal, the pressure is not uniformly normal to the chord of the arc, but is considerably inclined forward of the perpendicular, with the result that the lift is increased and the drift decreased. He stated it as follows:

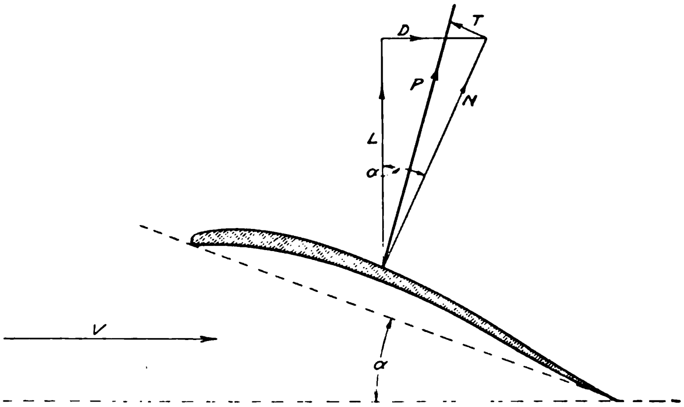

Fig. 20. Resolution of Force Diagram for a Curved Plane

> When a wing with an arched surface is struck by the wind at an angle a with a velocity V, there will be generated a pressure P, which is not normal, but is the resultant of a force N, normal to the chord, and of another force T, tangential to the chord.
>
> Taking A as the area of the wing, and .005 as the coefficient of air resistance, it is apparent that—
>
> $$N = n \times .005 \times A \times V^2$$
> $$T = t \times .005 \times A \times V^2$$
>
> Values of n and t, which represent constants used by Lilienthal, show the arched surfaces still possess supporting powers when the angle of incidence becomes negative, *i.e.*, below the horizontal. The air pressure P becomes a propelling force at angles exceeding 3 degrees up to 30 degrees.

As Chanute pointed out, this does not mean that there is no horizontal component, or drift, of the normal pressure N under these conditions, but that, at certain angles, the tangential pressure T, which would be parallel to the surface and only produce friction in the case of a flat plane, acts on a curved surface as a propelling force. The experiments of the Wright Brothers at Kitty Hawk, North Carolina, verified the existence of Lilienthal's tangential, and experiments conducted by them later in their laboratory further supported this fact, though their results differed from Lilienthal's at angles below 10 degrees. Fig. 20 illustrates the resolution of forces on a curved plane, *L* and *D* being the lift and drift as obtained from the effective pressure *N*.

Lilienthal prepared a table giving the values of *n* and *t* on an inclined surface, on a basis of $\frac{1}{12}$ curve from zero to 90 degrees, and a comparison of this with the experiments of Langley on flat surfaces exhibits at once the greater lifting effect of curved surfaces, though Wilbur Wright is of the opinion that Lilienthal's values are somewhat too large at angles below 9 degrees. Although many excellent treatises have been written on the subject, it is hardly possible with the present knowledge of aerodynamics to explain exactly what the significance of these values *n* and *t* are, or to bring them under any well-known set of physical laws.

An examination of the photographs of stream lines of air obtained by such experimenters as Marey, Hele-Shaw, and Mach and Akborn, suggests that a surface with a pronounced curve at the front would tend to produce a vortex action under the front edge, when the current of air is swift enough, and recent investigations indicate that such action increases the dynamic resistance enormously as the speed increases. In racing machines, therefore, the curved surface so widely used in slower machines is being gradually departed from and in its stead, a surface with a flat under side and a curved upper side, having considerable thickness at the center, is being substituted. The air stream is thus guided smoothly over the upper curved surface, while the lower flat face permits of a much easier flow, and consequently of a decrease of dynamic resistance, or drift. The decrease in the lift thus occasioned is compensated for by higher velocities due to increased motor power. Just how much the lift is decreased can be shown only by actual practice. This flattening of the under side of the supporting surface has a great disadvantage in that it tends greatly to lessen the stability of the machine.

Ratio of Lift to Drift. The ratio of lift to drift is of great importance in the design of aeroplanes, and the surface having the greatest ratio under working conditions is the most efficient from an aerodynamic standpoint, *i.e.*, it carries the greatest weight with the

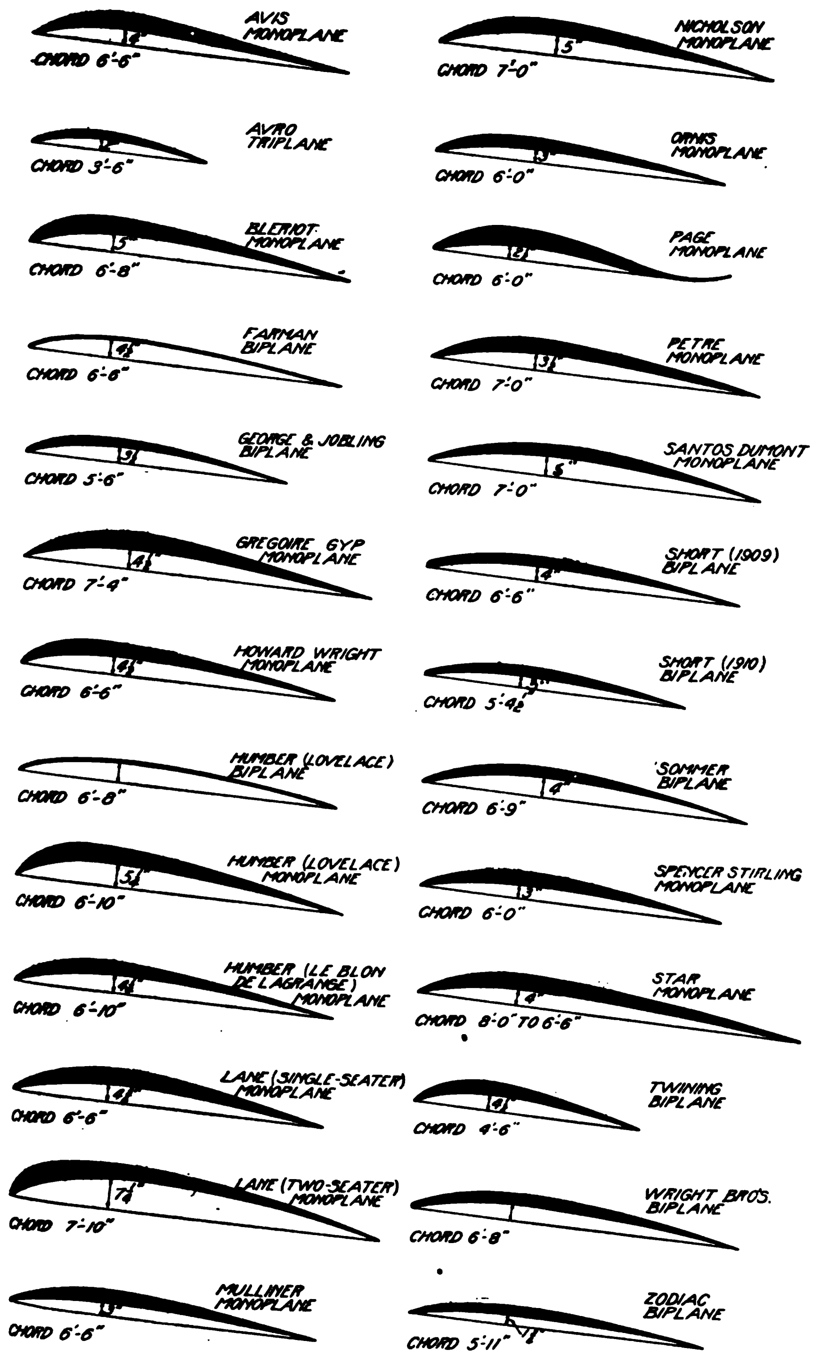

Fig. 21. Sections of Main Supporting Planes of Well-Known Types of Aeroplanes Shown in London, 1910

least power. The large value of the ratio for small angles shows arched surfaces to be the most economical in flight. The manner in which various prominent designers have worked out the problem in actual practice is illustrated by the comparison of the different sections of the supporting surfaces, or planes, of the machines exhibited at Olympia, London, 1910, Fig. 21. The experiments on the relation of sustaining power to head resistance, on various planes, show that a thick, curved plane is very efficient, as well as by far the most stable. The Antoinette monoplane is equipped with surfaces of this form. (See upper diagram, Fig. 28, in "Types of Aeroplanes.")

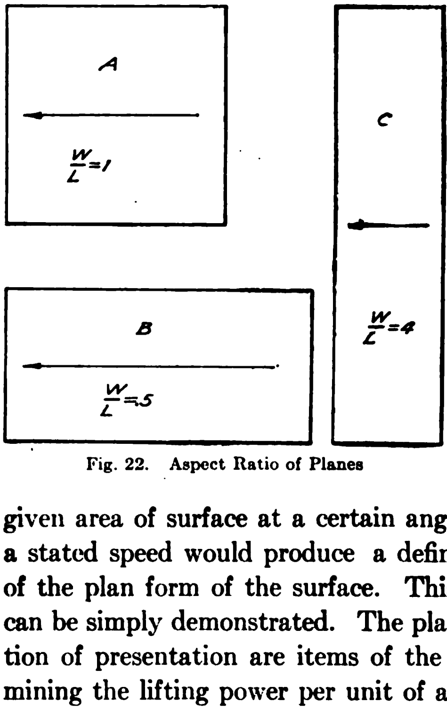

Fig. 22. Aspect Ratio of Planes

Aspect Ratio. "Aspect ratio" is the term commonly employed to indicate the ratio of spread, *i. e.*, width of the supporting surfaces, to their depth. It is a feature of greater importance than the curvature of the plane itself, in that it determines to a considerable extent the lifting power of the latter. At first glance, it would seem that a given area of surface at a certain angle of incidence and moving at a stated speed would produce a definite lifting reaction, regardless of the plan form of the surface. This is not the case, however, as can be simply demonstrated. The plan form and its aspect or direction of presentation are items of the greatest importance in determining the lifting power per unit of area. Obviously, the lifting or supporting reaction of the air upon a surface depends upon the amount of air displaced or acted upon by it in a unit of time. Fig. 22 shows three equal surfaces of rectangular plan form, varying in their respective ratios of width to length, the length being in each case measured parallel to the line or axis of flight.

If each of the three surfaces shown, *A*, *B*, and *C*, is given the same angle of incidence and is moved along its line of flight at the same speed, the amount of air acted upon in unit time (the measure of the relative supporting powers) will naturally vary among the three surfaces as the width of the presented edge. That is, for equal rectangular areas of supporting surface, at the same speed and angle of incidence, the supporting powers vary as the ratios of the widths to lengths along the axes of flight. In Fig. 22, then, if the surface *A* will support 1 pound, *B* will support .5 pound and *C* will support 4 pounds, all other conditions being identical. Of course, these figures are modified considerably by the heights and depths to which the air is acted upon by the passage of the surfaces, and, since these values vary directly but in reduced ratios, as the axial lengths of the compared surfaces, it will be apparent that *C* will not actually lift eight times as much weight as *B*. However, the rate of gain is very much higher than the rate of loss, as the width or spread is extended and the depth correspondingly decreased, as strikingly shown by the simple comparison just given. In the case of plane *A*, the aspect ratio is 1 to 1; in *B* it is .5 to 1, or what might be termed a negative aspect ratio; in *C* it is 4 to 1. By referring to "Types of Aeroplanes," it will be noted that the usual aspect ratio employed in actual practice varies between 5 and 7 to 1.

As a matter of fact, the efficiency of the supporting reaction increases almost indefinitely with an extension of the width to length ratio and in practice is limited only by constructional considerations. This is shown in nature by the extremely great spread of wing of the soaring birds as compared with their depth. For instance, the man-of-war hawk, a tropical marine bird, has a spread of wing of several feet while its depth is but a few inches (plane *C*). It is very rarely seen to move its wings in flight, but soars practically motionless at altitudes of several hundred to a thousand feet. The common black crow of northern latitudes, on the other hand, has a wing more closely approximating plane *B*, considering the upper edge of this to be the one presented to the air, instead of the left-hand edge as in the illustration. Birds of this class are slow and heavy fliers and have to flap their wings constantly.

Weight for weight, the structure of surface *B* can be made stronger than *A*, even as *A* is inherently stronger than *C*, and the limit of extension of the aspect ratio is determined only by strength considerations in the completed surface. Average practice in this respect places the ratio at about 6 to 1.

Skin Friction. By analogy with the great frictional resistance of a body in water, it would seem as if the friction of the air would also be considerable. This is termed *skin friction* and, in their experiments, many early investigators put it down as practically a negligible factor. Professor Zahn went into this thoroughly in 1903 and determined that the friction of the air on surfaces is an important factor. He expressed its general value in the formula $F = .0000158\, L^{.93} v^{1.05}$, where F is the frictional drag in pounds per square foot, L is the length of the surface in the direction of motion in feet, and v is the velocity of the air past the surface in miles per hour. The friction was found to be approximately the same for all smooth surfaces, but 10 to 15 per cent greater on extremely rough surfaces, which accounts for the care with which the supporting surfaces of an aeroplane are made smooth. It is now generally accepted that skin friction is an appreciable factor in the resistance of an aeroplane, amounting to, in an average-sized machine, from 10 to 15 pounds.

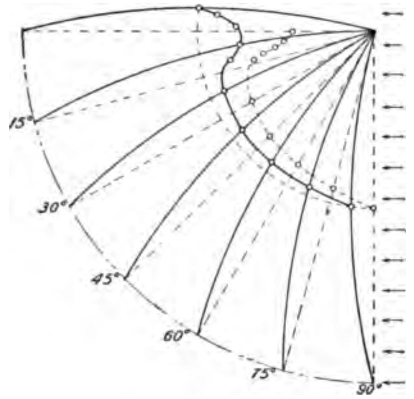

Fig. 23. Locus of Center of Pressure for Various Angles of Incidence for Curved Plane

In his experiments to determine head resistance and skin friction, Langley employed a rotating table with a collapsible arm holding a straight plane cutting edge of a given area, which could be moved at different speeds. He found that 256 square feet of skin-frictional surface developed approximately 1 pound resistance at a speed of 30 miles an hour. It was also found that cutting edges with straight surfaces and sharp angles developed almost double the resistance of a cutting edge with a spherical surface, while an elliptical surface had but half the resistance of a sphere.

Center of Pressure. Newton assumed that when a rectangular plane was moved through the air at an angle inclined to the line of motion, the center of pressure and the center of surface were always coincident. This is not the case, however, the center of pressure varying as the angle of incidence. Numerous experimenters investigated this with practically similar results, Langley's experiments with his "counterpoised eccentric plane" having been of this nature. But all these experiments were on flat surfaces and the movement of the center of pressure on curved surfaces is totally different. In deeply-arched surfaces, it moves steadily forward from the center of surface as the inclination is turned down from 90 degrees, until a certain point is reached, varying with the depth of curvature, Fig. 23. After this point is passed, a curious phenomenon takes place. Instead of continuing to move forward with a decrease of angle, the center of pressure turns abruptly and moves rapidly to the rear. According to Wilbur Wright, this action is due largely to the pressure of the wind acting also on the upper side of the arched surface at low angles. The action is unmistakable and has often been observed in practice; the reversal, which, according to Rateau, occurs as the angle of 15 degrees is approached, strikingly illustrates the difference in the conditions of pressure on a curved surface at low angles as compared with those of flat surfaces. A region of instability at 30 degrees also appears to be present in a curved surface.

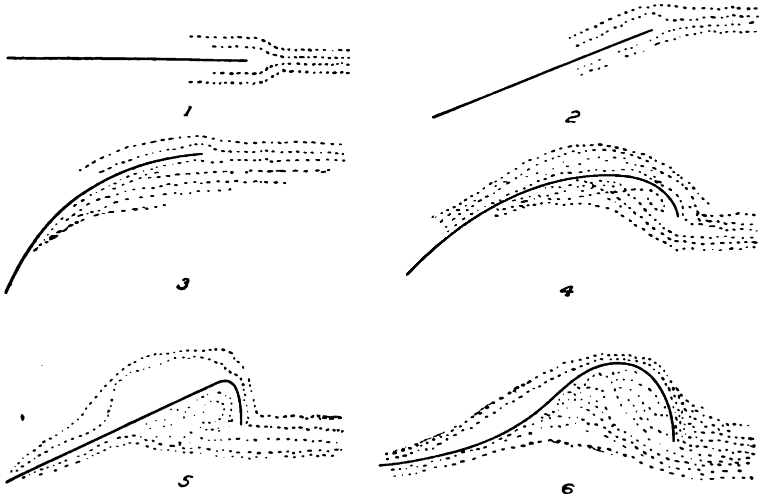

Fig. 24. Six Stages of Development of the Aeroplane Supporting Surface

Evolution of Curved Supporting Surface. The foregoing emphasizes the great importance of the proper curvature of the supporting surfaces of an aeroplane, and the evolution of this curve has been so minute and apparently so insignificant that its actual importance is not appreciated except by the experienced designers of machines. Going back to before Lilienthal's time, it may be said to progress in six stages, Fig. 24: *First,* the flat plane, held horizontally. *Second,* at an angle of incidence. (With neither of these was there any hold on the air.) *Third,* the true arc of a sphere was employed and with this curve the feat of lifting a man in gliding flight was first accomplished, due primarily to the fact that the air was not thrown off at such a sharp angle as in the straight plane. It caused the air to compress more and more to the rear of the curve, or moved the center of pressure backward. *Fourth,* the next step was to bend the forward edge of the arc downward sharply, forming a parabolic curve and causing the air to shoot upward at the point of contact, giving a powerful lift. *Fifth,* then followed the remarkable discovery that with a certain form, the upper surface of the plane exerts as much lift as the under side. This was obtained by taking a flat plane, held at an angle of incidence, and abruptly bending its forward edge downward, practically at right angles. By this construction, the air was thrust upward on the outer surface, while the air, rushing in underneath to fill the partial vacuum thus formed, exerted a powerful lift and, at the same time, was pushed forward, thus tending to diminish the head resistance. Still more important was the fact that the air, which was shot vertically upward by the butt edge of the curve, tended to raise the plane with it, giving an upward thrust or lift almost as great as that beneath the surface. In the final stage, the plane itself is no longer flat but curved upward as shown in the figure. In Fig. 24, these curves have been greatly exaggerated, but their influence will be apparent upon studying sections of the supporting planes of well-known types of machines.

The reason for not employing such exaggerated curves is because of the excessive head resistance that would be created. By far the greatest factor to be dealt with in the design of an aeroplane is the resistance to motion. On its elimination as far as possible depend the ability to fly, the speed, and the power efficiency. The total resistance may be divided into three parts: *First,* the head resistance of the framing and body; *second,* the drift of the plane or planes; and *third,* the frictional or skin resistance of the whole. To fly, this combined resistance must be overcome by the thrust of the propeller.

INTERNAL WORK OF THE WIND

Character of Air Currents. Before the researches of Langley showed its true nature, the wind was commonly assumed to be a homogeneously moving body. In other words, where not influenced by terrestrial obstructions, a wind blowing at a certain speed represented a uniformly-moving current of air, at any point in the body of which the moving air would be found to have the same speed and the same direction of travel. The subject is one of great importance to the aviator, and a knowledge of it, in outline at least, is essential to an understanding of many things that otherwise are inexplicable.

Instead of being a homogeneously moving body, Langley found that a current of air, even where movements only in one horizontal plane are considered, is always filled with amazingly complex motions. Some of these, if not in opposition to the main movement, are relatively so—that is, are slower, while others are faster than this main movement, so that there is always a portion opposed to it. These irregular movements of the wind, which take place up, down, and on every side, are accompanied by equally complex condensations and expansions, but it will be apparent that only a small portion, those occurring in a narrow current whose direction is horizontal and sensibly linear, could be recorded by the anemometer. However complex the movement may appear as shown by the records of the instrument, it is then far less so than the reality.

Movements of a Plane in Wind. *With Vertical Guides.* We will presently examine the means of utilizing this potentiality of internal work in order to cause an inert body wholly unrestricted in its motion and wholly immersed in the current, *to rise;* but first let us consider such a body (a plane) whose movement is restricted to a horizontal direction, but which is free to move between frictionless, vertical guides. Let it be inclined upward at a small angle (angle of incidence) to a horizontal wind, so that only the vertical component of pressure of the wind on the plane will affect its motion. If the velocity be sufficient, the vertical component of the pressure will equal or exceed the weight of the plane, and in the latter case, the plane will rise indefinitely.

For example, if the plane be a rectangle whose length is six times its width with an area of 2.3 square feet to the pound and an inclination at an angle of 7 degrees, and if the wind have a velocity of 36 feet per second, experiment shows that the upward pressure will exceed the weight of the plane, and the latter will rise (if between vertical, nearly frictionless guides) at an increasing rate until it has a velocity of 2.52 feet per second, at which speed the weight and upward pressure are in equilibrium. (Langley, "Experiments in Aerodynamics.") Hence, there are no unbalanced forces acting and the plane will have attained a state of uniform motion.

For a wind that blows during 10 seconds, the plane will, therefore, rise about 25 feet. At the beginning of the movement, the inertia of the plane makes the rate of rise less than the uniform rate, but at the end of 10 seconds, the inertia will cause the plane to ascend a short distance after the wind has ceased, so that the deficit at the beginning will be counterbalanced by the excess at the end of the assigned interval.

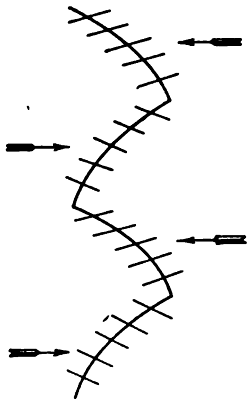

Fig. 25. Movements of a Free Plane in Air

Without Vertical Guides. Such a plane will be lifted and sustained *momentarily*, even if there be no vertical guides, or, in the case of a kite, if there be no cord to sustain it, the inertia of the body supplying for a brief period, the office of the guides or cord. If suitably disposed, it will commence to move under the resistance imposed only by its inertia to a horizontal wind, not in the direction of the wind, but nearly vertically. As the plane takes up more and more the motion of the wind, this inertia is overcome and the lifting effect decreases, that is, if the wind be the approximately homogeneous current it is commonly treated as being, and finally the plane falls. If, however, a counter-current be supposed to meet this inclined plane before its inertia is exhausted and consequently before it ceases to rise, it is only necessary to assume its revolution through 180 degrees about a vertical axis, to see that it will be lifted still higher without any other call for expenditure of energy, as its inertia now reappears as an active factor. Fig. 25 shows what might be assumed to happen to a model inclined plane freely suspended in the air, and endowed with the power of rotating about a vertical axis so as to change the aspect of its constant inclination, which need involve no theoretical expenditure of energy, even though the plane possess inertia. It is evident that the plane would rise indefinitely by the action of the wind in alternate directions. The disposition of the wind, which is here supposed to cause the plane to rise, appears at first an impossible one, but it becomes virtually possible by a method which we will now point out and which leads to a practicable one which *we may actually employ.* (It must be borne in mind that these experiments were carried out in 1893—ten years before the first flight of the Wright Brothers.)

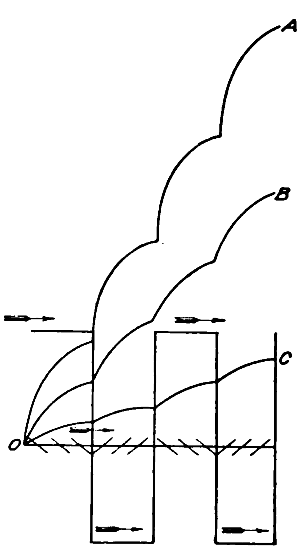

Fig. 26. Movements of a Free Surface in a Pulsating Wind

Behavior in Pulsating Wind. Fig. 26 shows the wind blowing in one constant direction, but alternately at two widely-varying velocities, or rather, in the extreme case supposed in the illustration, where one of the velocities is negligibly small, and whose successive pulsations in the same direction are separated by intervals of calm. A frequent alternation of velocities, united with constancy of absolute direction, has been shown to be the ordinary condition of the wind's motion; but attention now is called particularly to the fact that while these unequal velocities may be in the same direction as regards the surface of the earth, yet as regards the *mean* motion of the wind they are in opposite directions, and will produce on a plane, whose inertia enables it to sustain a sensibly uniform motion with the mean velocity of this variable wind, the same lifting effect as if these same alternating winds were in absolutely opposed directions, provided that the constant inclination of the plane alternates in its aspect to correspond with the changes in the wind.

It may aid in clearness of conception, if we assume a set of fixed co-ordinates, X, Y, Z, passing through O, and a set of movable co-ordinates, x, y, z, moving with the velocity and direction of the mean wind. If the moving body is referred to the first only, it is evidently subject to pulsations which take place in the same directions on the axis of X, but it must also be evident that if referred to the second, or movable co-ordinates, these same pulsations are in opposite directions. This, then, is the case we have just considered, and if we suppose the plane to change the aspect of its inclination as the direction of the pulsations changes, it is evident that there must be a gain in altitude with every pulsation, while the plane advances horizontally with the velocity of the mean wind.

During the period of maximum wind velocity, when the wind is moving faster than the plane, the rear edge of the latter must be elevated. During the period of minimum velocity, when the plane, owing to its inertia, is moving faster than the wind, the front edge of the plane must be elevated. Thus the vertical component of the wind pressure as it strikes the oblique plane tends in both cases to give it a vertical upward thrust. So long as this thrust is in excess of the weight to be lifted, the plane will rise. The rate of rise will be greatest at the beginning of each period, when the relative velocity is greatest and will diminish as the resistance produces "drift," *i.e.*, diminishes relative velocity. The curved line OB, Fig. 26, represents a typical path of the plane under these conditions.

It follows from the diagram, Fig. 25, that, other things being equal, the more frequent the wind's pulsations, the greater will be the rise of the plane; for since during each period of steady wind the rate of rise diminishes, the more rapid the pulsations, the nearer the mean rate of rise will be to the initial rate. The requisite frequency of pulsations is also related to the inertia of the plane, for the less the inertia, the more frequent must be the pulsations, in order that the plane shall not lose its relative velocity.

Soaring. It is obvious that there is a limit of weight which can not be exceeded if the body is to be sustained by any such fluctuations of velocity as can be actually experienced. Above this limit of weight the body will sink. Below this limit, the lighter the body is, the higher it will be carried, but with increasing variability of speed. That body, then, which has the greatest weight per unit of surface will soar with the greatest steadiness, if it soar at all, not on account of its weight, *per se,* but because the weight is an index of its inertia.

The student who will compare the results of experiments made with any artificial flying model, like those of Penaud, with the weights of the soaring birds, as given in the tables by Mouillard, or other authentic sources, can not fail to be struck with the great weight in proportion to wing surface which Nature has given to the soaring birds, compared with any which man has been able to imitate in his models.

This great weight of the soaring bird in proportion to its wing area has been again and again noted, and that without weight the bird could not soar has been frequently remarked by writers who felt that they could very safely make such a paradoxical statement in view of the evidence nature everywhere gave that this weight was in some way necessary to rising. But these writers have not shown, so far as I remember, how this necessity arises, and this is what I now endeavor to point out.

The evidence that there is *some* weight which the action of the wind is sufficient to sustain permanently under these conditions in a free body, has a demonstrative character. It is obvious that, if this weight is sustainable at any height, gravity may be utilized to cause the body to descend on an inclined course to some distance. This is now a matter of such common experience that French aviators term it *volplane,* the action itself already having been anglicized as "volplaning." Seventeen years after Langley wrote it, Drexel gave a striking example of its truth by volplaning from a height of more than 9,000 feet, reaching the earth at a point 15 miles distant.

We have already seen how pulsations of sufficient amplitude and frequency, of the kind which present themselves in nature, may, in theory, furnish energy sufficient not only to sustain but actually to elevate a heavy body moving in and with the wind at its mean rate. It is easy now to pass to the practical case, exemplified by the bird, which, soaring on rigid wings, but having power to change its inclination, uses the elevation thus gained to move against the wind without expending any sensible amount of its own energy. Here the upward motion is designedly arrested at any convenient stage, *i.e.,* at each alternate pulsation of the wind, and the height attained is utilized so that the action of gravity may carry the body by its descent in a curvilinear path, if necessary, against the wind.

As the remainder of this particular study of Langley's is devoted to demonstrating the practicability of the theories here propounded, it would not be profitable to follow them any further. They are now a matter of more or less common knowledge, having long since been raised from the realm of theory. But the influence of the "internal work of the wind," or rather its "internal character" if it may be so termed for purposes of illustration, upon the actual operation of the aeroplane, is of the greatest importance, and moreover it is something about which there is yet a great deal to be learned.

Air Holes. The deaths of Moissant at New Orleans, and Hoxsey at Los Angeles, on December 31, 1910, gave rise to a great deal of discussion regarding the uncertain character of the atmosphere as affected by the wind, and emphasized the fact that very little is actually known concerning it. Both being experienced aviators of a conservative type, it was difficult to account for the accidents (nothing apparently having gone wrong with either machine) except on the ground that the machine had suddenly dropped into a depression in the atmosphere, causing it "to stand on its head" and fall. The latter theory is supported in Hoxsey's case by an instantaneous photograph of his machine taken at the moment it started to fall, and showing it in apparently perfect condition, coming down in a perfectly vertical line. A more plausible explanation, however, is that Hoxsey, having just descended from a great altitude to within 500 feet of the earth, was overcome by the sudden change in pressure (see article on "Altitude"), and lost consciousness. In so doing, his body may have pitched forward against the lever of the elevating rudder, and so operated the latter as to head the machine vertically downward. This could not have been so in Moissant's case as he had not been up more than a hundred feet, the accident being ascribed by some of his fellow aviators to the fact that he attempted to land with the wind, contrary to the usual custom.

Whether or not either of these fatalities was due to these "pockets" or "holes" in the air, as they have come to be popularly termed, will never be known, but the fact that the atmosphere (wind) instead of being a homogeneous current of air, the character of which may be depended upon, is a complex mass of points of high and low velocity, or none at all, is an element that must be contended with by every aviator. Unlike the sailor, he can not see an unusual wave coming, nor can he determine deeps and shallows by the appearance of the surface. It is only when the wave or gust has struck the machine, or the machine itself has passed into one of the pockets in the air, that the aviator knows how big or strong it is going to be, or how far the sudden fall in pressure due to passing over a calm spot will drop the machine. One of the troubles of aviators at exhibition meets is that the spectators do not appreciate the danger of these wind waves and holes and so expect them to fly in weather that is really dangerous, although it may appear fine.

Effect of Eddies and Waves. On an open plain of considerable extent, such as that at which the aviation meets at Rheims are held, there is nothing to interfere with the wind and it blows more steadily, though as Langley has pointed out, the existence of swirls and eddies in the wind is independent of the influence of obstructions. It is well known, however, that the presence of obstructions gives it a totally different and far more dangerous character. Where there are hills, banks, and trees all around, the wind, even when blowing comparatively gently, comes in dangerous waves, swirls, and eddies, just like the eddies and whirlpools in a stream that has rocks or other obstructions to impede the flow of the water.

To properly understand the effect of these waves and eddies on an aeroplane, the theory of the flight of the latter must be borne in mind. The machine is sustained in the air, because the speed at which it is driven produces a pressure under its supporting surfaces exceeding its total weight; hence, the pressure lifts it. If driven faster, the pressure is increased and its sustaining power is greater; if driven slower, this is decreased and the machine tends to fall. In fact, we have the anomaly of prizes being offered for machines that are able to fly slowly. For example, if a machine be capable of a speed of 40 miles an hour, this represents a close approximation of its critical speed—in other words, it must fly that fast or not at all. By speeding up the motor, it may be able to fly a few miles an hour faster, but it can not fly much slower and still sustain itself in the air —in the case of the 40-mile-an-hour machine, probably not much less than 34 miles an hour.

Owing to its weight, ranging from 500 pounds in the case of a small monoplane, up to almost a ton for some of the largest biplanes, the inertia due to the high speed is very great, and the machine will accordingly not change its rate of travel suddenly. Therefore, assume a machine flying at 40 miles per hour over the ground in a gentle wind, and suppose that a gust traveling 10 miles an hour faster than the wind, against which it has been going, strikes it. The machine can not slow down but simply charges into that gust at 40 miles an hour. Consequently, the pressure on the wings is increased and the machine rises exactly as the soaring birds do under similar conditions. But consider the effect of opposite conditions. Assume the machine to have reduced its speed in relation to the earth, so as to get to its proper flying speed in relation to that gust of wind. Presently, it goes right through that gust and into the lull on the other side, just as a boat rides over a wave and falls into the trough between the waves. Now it is flying too slowly for the area of comparative calm that follows the gust; the pressure is decreased and with it the lift, so that the machine drops—if not very high it may strike the ground, as has often been the case. If high, it merely drops until it picks up its normal speed again and increases the pressure accordingly. The sudden drop is very disconcerting and is the cause of numerous accidents, particularly where the machine is not up high enough to permit of falling into one of these "holes in the wind" without coming to earth.

Relative Speed of Wind and Aeroplane. The speed of a machine through the air has little to do with its speed over the ground. The important thing is its speed with relation to the wind against which it is traveling—or rather attempting to travel would be better, as strikingly illustrated by the experience of Johnstone and Hoxsey trying to make headway against a gale of wind at the International Meet at Belmont Park. The wind was blowing 40 to 50 miles an hour, exceeding the speed of which the Wright biplanes were capable. They accordingly simply headed directly into the wind and were blown backward by it, at times remaining perfectly motionless in the air, with regard to the ground, when the wind and the thrust of the propellers equalized each other, gaining a little at each lull, and losing more with each stronger gust, Johnstone traveling more than 40 miles in this manner, while Hoxsey went about two-thirds of that distance before alighting. Hence, it is easy to appreciate that the 40-mile-an-hour machine, which can make that speed in still air, can travel only 20 miles an hour against a 20-mile wind, and can travel 60 miles an hour over the ground with a 20-mile wind.

Assume the machine to be flying in a gusty wind; it is making 40 miles an hour and is in a gust traveling 20 miles an hour. The biplane is going 60 miles an hour and will accordingly travel through the gust in a short time into slower air, traveling at, say, 10 miles an hour. The machine is then going 60 and the wind only 10 miles, so the machine is going 50 miles an hour faster than the air when it should be going only 40. Consequently, the pressure under the planes increases; the machine rises suddenly till the rush of the extra momentum is expended; and then settles down to its proper speed of 40 miles an hour through the wind, plus the 10-mile-wind speed, which makes 50 miles an hour.

Then the machine runs through the slow wind and overtakes another patch traveling at, say, 20 miles an hour. This time the machine is doing 50 miles an hour, and only 30 an hour more than the wind, which is not enough to keep it in the air, so the whole machine falls until the thrust of the propellers has given it sufficient speed to pick up the extra 10 miles an hour required to attain its critical speed of 40 miles an hour, and by that time it will be going 60 miles an hour over the ground again.

Certain Effects on the Wind. Another important thing to understand is the effect of different obstructions on the wind. A wind blowing against a hillside is bound to blow up along its sides and the wind next to the ground will be compressed by the other wind meeting it, so that when it gets to the top of the hill it will expand, and some of it will blow level along the top of the hill and some of it will continue to rise. An aeroplane falling off the top of such a hill—the bow of a war vessel, as an example—would be lifted quite easily. Again, when a wind strikes a cliff face, the compression may be so great that the wind will rise straight up and curl over, just like a wave, while close to the edge there might be no wind at all. An aeroplane flying in such a wind might well be caught in the "curlover," and dashed to the ground; but if it got as far as the edge, it would be lifted by the up-draft.

Downward drafts also occur and these are dangerous to aeroplanes, because if the pressure suddenly comes from above, as in flying into such a wind, it is difficult to increase the speed quickly enough to counteract this by generating sufficient pressure beneath the planes. Only high speed and a powerful motor would make it possible. The commonest kind of down-draft is formed when the wind blowing over the top of a hill finds the air in the valley at a lower pressure, and consequently, due to the pressure behind it, swoops down into the valley. Curtiss experienced numerous downdrafts of this kind in his flight from Albany to New York down the Hudson River valley. A less common kind of wind is met with when a cold wind over the sea descends to a cliff edge to replace air that is being drawn away to fill the place of hot air ascending from the heated earth farther inland. This is the phenomenon that causes sea breezes and land breezes alternately at different times of the day.

This uncertain character of the atmosphere—the sudden and extreme variations in the speed of the wind, and frequently in its direction as well, is something for which the aviator has to be constantly on the alert. It is one of the chief reasons why it is safer to fly at a height than comparatively near the ground, for then, unless the aviator has been entirely demoralized by the sudden drop, there is time for him to regain control of the machine before striking the earth.

THEORY OF AVIATION

PART II

GLIDING AND SOARING

GLIDING FLIGHT

If it were rumored that Edison was conducting secret experiments with a view to making a new type of electric generator out of a block of wood, there would doubtless be columns about it in the daily papers and much of what was written would be regarded by many as having a basis of fact, if not the whole truth of the matter. Exactly the same thing happens when the Wright Brothers set out to conduct experiments, the press reports of the gliding flights made at Kitty Hawk, North Carolina, in the fall of 1911, forming an aggravated instance of this kind. The tenor of practically all the reports was to the effect that the Wright Brothers were seriously engaged in trying to perfect a machine that would fly without power, and a wealth of detail accompanied the description of its success in accomplishing this. Some went so far as to state that the new Wright machine was of the wing-flapping order and that the solution of the problem of flight without power was already as good as achieved, as the machine was capable of hovering indefinitely over a selected spot—also that it was capable of imitating the soaring flight of the larger birds. The customary reticence of the inventors themselves was, of course, regarded as further evidence of mysterious and marvelous achievements of too great import to be talked about publicly. Undoubtedly, this attitude on the part of the press and public has been inspired largely by the vague idea that soaring flight pure and simple is an impending development in this field of engineering. In other words, that the time is close at hand when man can finally claim to have succeeded in endowing himself with the power of the birds. To those who have given the subject any serious thought or study, the utter fallacy of such claims will be apparent, and the Wright Brothers themselves would undoubtedly be the last to even intimate it. As at present constituted, human life is possible only within a comparatively short distance of the earth, as restricted by the necessary density of the atmosphere, and as long as man stays in that atmosphere he is subject to the influence of gravity. To overcome that influence, power is indispensable, and in the case of the gliding aeroplane, this may take two forms, viz, the force of the wind, and the impulse that may be obtained by taking advantage of gravity itself.

The sight of a glider actually advancing into a 50-mile wind, hovering stationary (with reference to the earth) over one spot for ten minutes and making a short, circular flight which began and ended at the same spot, might well give rise to such stories of the advent of the aeroplane without a motor as appeared at the time, but, as a matter of fact, the chief object of the Wrights was to test the stability of a new type of tailless machine and at the same time to carry further the exhaustive experiments in free flight which were made for such a lengthy period prior to the actual building of the first power machine.

New Wright Glider. The new glider is a characteristic Wright biplane type with a span of 32 feet and a chord of 5½ feet, having a total weight of about 145 pounds. The wings appear to be identical with those of the standard Wright power-driven machines and are correspondingly thin and flat in curvature, though it may be quite possible that the supporting surfaces themselves were also made the subject of tests. The two surfaces are separated by eight pairs of vertical struts of the same form as those ordinarily employed in Wright construction. They space off the total span into seven sections and, as formerly, the central span is made narrower than the others, while for convenience in shipping it is made separable from the others. The operator is seated directly in the center of the machine on the forward edge of the lower plane. The center section and the two sections on either side of it are rigidly trussed in all directions by diagonal bracing wires, leaving the first two sections from each wing tip free to undergo the distortion involved in warping. The wings are warped and the double vertical rudder is operated by a single lever with a jointed head, placed at the right of the aviator, while the elevator is worked by a lever at the left. Both the vertical and horizontal tail surfaces are carried on a light skeleton box girder similar to that employed on the power machine. In fact, the new glider does not differ materially from the Model "B" Wright machine, except for the single vertical fin, about a foot wide, which extends the entire height of the space between the main planes and is placed just in front of them to the left of the aviator, this being simply a substitute for the fin-like stabilizing surfaces employed on all except the original type of Wright machine which had the elevator some distance forward of the main planes. The runners are similar in construction but have been made so low as to barely keep the lower main plane off the ground, this presumably having been done to reduce the head resistance to a minimum. To secure accurate longitudinal balance of this experimental glider, an outrigger or single stick extending forward was employed. Attached to this was weight which could be conveniently varied in quantity or shifted in position to give greater or less leverage.

Gliding Flights at Kitty Hawk. While the results achieved with this new glider have been of a startling nature, a little study indicates that they differ only in duration and in the greater skill in maneuvering developed by several years of actual flying, from those carried out in 1903 on the same spot. The Wright Brothers have succeeded in making glides that far exceed anything done in this line before, in attaining greater heights and greater distances, and in staying aloft for a longer time, but that most of this must be attributed to the great skill they have acquired in the eight years constant flying of their power machines that have elapsed since the former gliding experiments were made, rather than to any radical innovations in the machine itself must be apparent. Eight years ago, the number of really expert gliders to be found among the entire body of experimenters could probably have been counted on the fingers of one hand, and, of this small number, the Wrights would naturally head the list, having been the only investigators after Lilienthal to carry out a consistent series of experiments of this kind to their logical conclusion. The majority of investigators were bent upon taking what appeared to be a direct short cut by immediately building a power machine, which neither they nor anyone else knew how to fly, even if it were capable of such a feat, and many others are wasting time and effort in the same misguided manner today.

The skill that the Wright Brothers have since developed in the control of their power machines was strikingly apparent in the handling of the new glider. With consummate ease, Orville Wright glided off the top of the hill against a 50-mile gale, and succeeded in not only soaring over one spot for a period of ten minutes, but in actually advancing against the wind. This great flight was made over the side of the hill facing the wind so that the air currents must have had a decidedly upward trend. The distance covered was a quarter of a mile and the height attained was estimated at 200 feet above the ground. At times, the machine would rise or fall without horizontal displacement, and then again it would glide ahead or drift back, as fluctuations in the wind facilitated these maneuvers. At all times, it exhibited the positiveness and certainty of control for steering, balancing, and landing that is characteristic of a power machine. But that even these features of the performance are neither novel nor new, except in the degree of their accomplishment, is attested by the Wright Brothers' own reports of their first gliding experiments communicated to the Smithsonian Institution and to the Western Society of Engineers, in which mention is made of brief hovering, gain of altitude, and advancing against the wind by taking advantage of winds blowing up a slope. The action of a wind blowing up a slope or meeting an obstruction is explained under "Internal Work of the Wind."

Glider Sustained without Apparent Motion. Popular misconception has naturally centered about the ability of the machine to hover over a certain spot, while the fact of being able to actually advance against a 50-mile-an-hour wind has been made the basis of the tales regarding the motorless aeroplane of the near future. It is a matter of common knowledge that to secure sustentation, the aeroplane must be in continuous forward movement, but what appears not to be so well known is the fact that this movement requires to be only *through the air,* as explained in "Building and Flying an Aeroplane," and sustains only a most incidental relation to the ground. It follows that if the whole body of the air is moving in the form of a wind across the earth's surface at a speed of 50 miles an hour, an aeroplane will be normally sustained by it without making any progress whatever with reference to the ground. Relatively to the air, it is the same as if a power machine were being driven at 50 miles an hour in a perfect calm. Conversely, if the aeroplane travel with the wind, it must fly at its normal speed or greater owing to the following wind, and to this there will be added the wind's speed, so that it will be traveling over the ground at a rate in excess of 100 miles an hour. This actually happened to Lieutenant Conneau in the Paris-Madrid race. Of course, the extreme conditions of a complete doubling or nullification by the wind of an aeroplane's speed are unusual, but less extreme conditions involving the same principle are common to all aeroplane flights not undertaken in a dead calm, and in which there are all degrees of minor additions to or subtractions from the actual speed of the machine by the effect of the wind.

Where the rising and advancing are concerned, it is due partly to the peculiar phenomena often called "Lilienthal's tangential" that a glider with cambered planes can not only remain stationary, but in a wind of great enough upward trend can be made to actually advance by taking advantage of the motive power of the wind itself that is blowing against the glider. This may appear to border on the miraculous and to savor strongly of perpetual motion, but it must be borne in mind that the huge energy of the rising current itself is the source of power. The phenomenon referred to is merely that at certain angles the total air pressure acting on a plane ceases to act in a line normal to the plane or its chord, and instead the line of action of this force takes a position well in front of the normal, the pressure thus materially acting in the dual rôle of *a supporting and propelling force.* Octave Chanute, as early as 1909, pointed out in a masterly way the manner in which this problem of soaring could be solved and many experts who have since investigated the subject are convinced that it is a feasible one.

Lift and Drift Ratio. Another point that may be made clear in this connection is the fact that any wing surface, at a fixed angle and with a constant loading, has a certain critical speed at which it is normal for it to travel and at which the resistances it opposes to movement through the air are a certain fixed percentage of its weight —the "lift to drift ratio" referred to under "Aerodynamics." To overcome the drift resistance, it is necessary to produce either propeller thrust of corresponding magnitude or to resolve the weight of the machine itself into a propelling component by coasting it downhill on the air, so to speak. It will be evident from this that the

Wrights' experiments also may have had this important investigation as one of their objects, viz, the improvement of the lift to drift ratio—in a glider, by flattening the angle of coasting necessary to sustain it aloft, and in a power machine, by reducing the amount of propeller thrust and consequently the size of the motor required. A less apparent but none the less real advantage of flattening the gliding angle inheres in the possibility it opens up of taking extensive advantage of rising currents in the atmosphere as a means of assisting in the propulsion of aeroplanes; for such currents, while common, are not ordinarily of sufficient magnitude to sustain machines of such excessively abrupt gliding angles as are now universal. In thus taking advantage of rising currents, in much the same manner that is probably employed by the large soaring birds, the chief essential must always be a gliding angle so flat that the machine loses altitude slower than the air rises, thus continuing indefinitely to coast down an invisible hill that rises faster than the machine slides down it.

It was also generally reported that one of the chief objects of the Wright Brothers' experiments was to test out an entirely new system of automatic balancing. As a matter of fact, they had actually intended to test the pneumatic devices patented in 1909 and described in "Automatic Stability," but the experiments were confined to gliding flights with the usual warping control to preserve lateral balance. During the course of these flights, a curious accident happened. After rising from the side of the hill about 20 feet, the heavy rear rudder appeared to become uncontrollable and to make the glider so "tail heavy" that it began to turn over and start backward, whereupon Wright climbed to an upright position of safety on the overturning machine with such excellent judgment that, when it struck the ground and smashed, he emerged unhurt. This experience suggests that it is a mistake to strap the aviator to his seat as is done in many of the monoplanes, and that frequently accidental injury might be avoided by a good use of similar coolheadedness in time of danger. Though the results attained are astonishing to many, those familiar with the nature of air currents expect even more startling performances at an altitude three to four times as great, as demonstrated by the experiments of Professor John J. Montgomery in California several years ago.

Montgomery's Gliding Experiments. Professor Montgomery was one of the pioneer investigators in the gliding field, his first experiments having been made from 1883 to 1886, when he built three machines of the flapping wing order—needless to add, without much success. Then he constructed a glider with its supporting surfaces modeled after the gull's wing, following nature blindly, as the reason for the downward curving surface of the attacking edge of the wing was not understood. This machine had a spread of 20 feet and a depth of 4½ feet, thus forming a close approximation to the aspect ratio that has since been determined as the most efficient for a glider. Success attended the experiments with it from the start, the first trial resulting in a glide of 600 feet; subsequently a great many experimental glides were made with it until its shortcomings made further trials risky. Though this first Montgomery glider was a success in one respect, it was defective in equilibrium, and its maker again resorted to nature for the solution of the problem. Close observations of vultures were made and the characteristic twisting of the wings in soaring flight was noted. A second glider was accordingly built in 1885, but while the principle of equilibrium as found in the bird's wing was followed, the form of surface was departed from as it seemed unreasonable that the wing should be inclined downward at the front. The second machine was accordingly made with flat surfaces. It was somewhat larger than the first and to afford lateral stability, each wing was hinged diagonally. This diagonal hinge allowed the "flaps" thus formed to yield to undue pressure on either side. These flaps were held in a normal position by springs. If the wind pressure became excessive, the flap of that wing would yield a little. In addition to the springs, the saddle was constructed with an upright to which wires running to the rear portions of the wings were attached, so that the operator could lean to one side or the other, giving a greater depth of curvature to one wing than to the other, but not giving different angles of incidence to the wings as the Wrights do. Ader's "gauchissement" (twisting), for which the French claimed so much, was the same effect; so that neither was an anticipation of the principle of warping as effected by the Wright Brothers, though many claims of this have been made for them.* The

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*It is significant that none of these claims was put forth until about 1907–1908, when the details of the Wright invention had become generally known.—Ed.

control of this machine proved excellent but its gliding ability was far inferior to the first, so that the curved wing surface was again returned to in the building of the third glider, with the exception, however, that its maker could not bring himself to believe that the downward curving surface in front was correct, so that a compromise was made by turning the front edge up a little, the remainder of the wing being similar to that of a vulture. The two wings were placed at a dihedral angle. In this glider, the warping principle was carried out in a different way. A lateral beam was placed along the front of each wing, and these two wings were capable of being rotated in a socket in the frame extending backward to the tail. Wires from the rear of each wing ran to levers—one for each wing—placed at the right and left hands of the operator, who sat on a saddle as in the previous gliders. With the aid of these levers, either one or both of the wing tips could be depressed, placing the machine under perfect control regardless of whether the wind was regular or gusty, the angle of the wings being changed to meet varying conditions. This glider had an even larger surface than the second one, but was inferior in lifting power even to the first glider with its true wing surface. Professor Montgomery then concluded that he had not succeeded in attaining the proper form of surface, and further that little or nothing was known of aerodynamics. As a matter of fact, there was practically no data of any value extant at that time, so that a search of existing records did not bring anything worth while to light. The machine was accordingly dismantled and a study of the problem undertaken from the beginning, to ascertain, if possible, the laws of aerodynamics determining the proper form of surface to give such phenomena as the soaring of birds. In 1886, Professor Montgomery constructed a whirling table consisting of a couple of rails fastened together and mounted on a pivot. Surfaces of various forms were fastened to the ends of this and the table whirled rapidly to study their movements. Right from the start, a peculiar phenomenon was noticed, suggesting that something was taking place in advance of the surfaces, and in order to test this, thistledown was scattered so as to determine the direction of the wind. Having learned this, a large barn door was set on the ground at an angle of about ten degrees and a reaction of the wind in front of it was immediately noticeable. Instead of the wind coming in a straight line, it traveled in a gradual curve and rose to strike the surface, indicating that the surface had an action on the wind in front of it, making plain the reason for the curving surface of a bird's wing.

Professor Montgomery resumed his investigations in 1903 and, having discovered the fundamental principles, was enabled to put them into practice in the machines he built. These were designed strictly along scientific lines and were tested in various ways. A cable was stretched across a 150-foot valley, and by means of cord, different models were liberated from that height in every possible way, head down, tail down, and upside down. In every case, they would glide safely to the ground, regardless of the manner in which they had been liberated. In all of these models, the warping idea, developed in 1885 and 1886, was employed, and having found that they were perfect in equilibrium and control, large machines patterned exactly after the models were built. To test these they were elevated on a cable between poles and were dropped alone and with weights. They were then tried in actual gliding flights, and it was unexpectedly discovered that they would respond very rapidly to a change in the wind. The hill employed as the scene of the flight, had a cañon across the bottom of it and it was found that while the wind blew directly in the glider's face as he started down, it was blowing along the cañon at right angles, and as soon as the machine came under its influence it was whirled rapidly to the right, but was not upset. For the purpose of developing the machine further, and at the same time of exhibiting it, the services of a parachute jumper with a hot-air balloon were secured. Professor Montgomery's idea was to commence experimenting by raising a man a short distance in the air and dropping him, but the parachute jumper insisted on going up at least a thousand feet for the first trial. The machine was accordingly so adjusted that it was impossible for him to get control of it and thus make a mistake and fall, clamps controlling the tail and wings giving a certain limited action, however. The first trial resulted in a beautiful glide, and then more liberty of action was allowed in the adjustments, and the hot-air balloon carried the glider to a height of three thousand feet. The instructions to the operator were to return to the starting point, but as he cut loose from the balloon, he lost his direction and started to fly in the opposite direction, but after a few minutes realized his mistake and made a fine sweep, passing through two or three clouds and finally circling to earth. In 1905, one of Professor Montgomery's parachute jumpers (Maloney) was killed through an accident to the machine in starting from the ground. Hot-air balloons rise very quickly and it was necessary to provide some means of retarding their upward rush. This was effected by ropes running through rings, and in Maloney's last flight one of these ropes caught in the machine. A warning was shouted that the glider had been broken, but the operator evidently did not hear it. He cut loose from the balloon at a height of about four thousand feet, when the machine immediately turned over and he descended with the machine upside down. Apparently, the fall was not any faster than that of a man dropping in a parachute, and when examined no broken bones or wounds were found, the physicians concluding that he had really died from heart failure. The San Francisco disaster put a stop to further experiments for several years, and when resumed they were brought to a close by the accidental death of Professor Montgomery himself in October, 1911, while making a glide at Evergreen, California. The machine was a monoplane glider, and for getting a rapid start with it, a runway of grooved tracks had been built down the side of the hill. A gust of wind caught the machine head on and dashed it to the ground.

SOARING FLIGHT

Countless theories have been offered in explanation of the phenomenon of soaring flight, but from the great number that have been advanced only two appear to afford a plausible solution of the problem. One of these is the quite common conception of soaring flight as being made possible by rising air currents; the other is the action and reaction theory of Professor Montgomery just described. The latter, though difficult to understand, is so thoroughly in accordance with the phenomenon that actually takes place as to leave little doubt of its accuracy. It is quite evident that birds do take advantage of rising currents to perform certain feats, but soaring flight is not dependent upon them.

Early Observations. *Andrews.* E. F. Andrews has observed that gulls following a steamer traveling against a stiff head wind, could not soar fast enough to keep pace with the vessel and would accordingly flap their wings until they reached the rising current deflected from the deck. They would then decrease the angle of their wings, reducing their head resistance and increasing their speed to that of the ship. At other times, when running with the wind, numbers of them were observed soaring about the vessel in wide circles, rising and falling, and always without a stroke of the wings. Under these circumstances, it would be impossible for them to take advantage of a rising current caused by the ship, and a local rising current in midocean would not alone be highly improbable, but it would not travel with the ship as the birds did. Further observations have demonstrated that a bird can soar upward on motionless wings without the assistance of a rising current. For instance, Andrews closely watched a turkey buzzard sailing over a field at a height of about fifteen feet. The big bird flew to within a very short distance of the observer and then without once flapping his wings, sailed upward to a height of a hundred feet or more in less than half a minute and continued to soar off until lost in the distance. Releasing, immediately afterward at the spot where the bird had risen, some light cotton fiber provided for the purpose, failed to reveal any rising current of sufficient strength to have any marked effect on the bird, as the cotton quickly fell to the ground within a short distance from the place it was liberated. Wilbur Wright is sponsor for the statement that the Wright biplane glider will glide over the face of a hill whose angle is so flat that turkey buzzards in order to fly over the same course will be compelled to flap their wings. But as the result of his observations, Andrews is of the opinion that the birds in question were probably not real turkey buzzards, as there are three species of vultures found in the southeastern states, viz, the carrion crow, the black vulture, and the turkey buzzard. The only distinguishing feature of the last-named variety is its slightly greater size and its red head, the heads of the other two species being black. The flight of the turkey buzzard is much superior to that of the black-headed members of his family. It is very seldom that he flaps his wings and when he does, the effort required is apparently so great that not more than three or four wing strokes are possible without stopping for a rest. The other two species of vulture do not possess the wonderful soaring ability of the turkey buzzard, and on this account it is necessary for them to flap their wings at short intervals throughout their flight.

Andrews' observations have included numerous instances in which turkey buzzards have made glides terminating several hundred feet higher than the starting point, when all the means at his disposal failed to reveal any rising current, while Victor Lougheed is responsible for the statement that he has seen a condor rise from a fence post in California and soar over the mountains without the stroke of a wing, when no rising current was perceptible. These observations seem to prove that a force like gravity can act on a body such as that of a bird in such a manner as to make it rise against the force, just as a sailboat moves against the force which is propelling it. Andrews has further verified his theories by carrying out experiments with a glider towed behind an automobile on the beach at Daytona, Florida. When the tow rope was slackened, the machine would commence to glide at a very flat angle, and flights as long as two miles were made behind a machine in this manner. It was intended to carry the experiments further by releasing the glider and soaring to earth, but an accident prevented this. The experience of both Andrews and other experimenters before him, who have tried towing a glider behind an automobile, has been such as to afford a warning to the student to strictly avoid all forms of towing flight. It is distinctly dangerous, as a machine which would be perfectly safe, if free, is made as erratic as a child's kite, the moment a rope is attached to it.

Historical Records. Soaring flight must not be confused with volplaning, or gliding downward by taking advantage of the pressure of the air beneath a plane to resist the force of gravity, and at the same time taking advantage of gravity itself to gather momentum and make short upward shoots, thus gaining horizontal distance. Soaring may be described best as gliding by the force of the wind without loss of altitude, or as shown by the ability of the turkey buzzard and condor, with a voluntary increase in altitude when desired. Human volplaning has been so far perfected as to no longer be a novelty, if indeed it does not surpass the master performances in nature. But human soaring is a much-neglected art, though capable of astonishing development, which may now be cultivated with enhanced facility by reason of the increased efficiency of the glider and the aeroplane.

The permanent art of passive flight dates from Lilienthal's experiments near Berlin in the early nineties, though long previous to that time some wonderful feats of gliding and soaring of both men and models were reported by reliable witnesses. Lilienthal made numerous glides several hundred feet in length down hill slopes, sometimes pausing in the air or rising considerably above the level of his launching place, while at times he wheeled about and returned almost to the starting point. He was succeeded by various disciples who improved the control of the glider and to some extent its efficiency. Professor Montgomery, a contemporary rather than a disciple of Lilienthal, after twelve years of study, launched a glider and aeronaut from heights which far surpassed in altitude and endurance all gliding records up to the present time. The record for volplaning in a power machine, which really becomes a glider when the motor stops, is held by Lincoln Beachey, who glided sheer down to earth in a Curtiss biplane from an elevation of 12,654 feet, during the Chicago Aviation Meet in 1911.

The records for soaring are briefer and some are not so well attested. In 1859, Captain LeBris, in a glider patterned after an albatross, soared 300 feet in the air and descended safely. This is given on the authority of De Landelle who wrote a history of aeronautics published in 1884. Mouillard is reported by Chanute to have soared 138 feet over a prairie after an initial run and jump across a roadside ditch. The glider in this case was strapped to his waist, the trials taking place about 1890. During the gliding experiments of Chanute and Herring, one of the operators was raised by the wind to a height of about forty feet and then landed almost in his tracks without serious shock. Also, lateral glides along the hillside were made, one forty-eight seconds in duration, which showed the possibility of patrolling to and fro in such places. Atwood relates that while flying over a mountainous country, he once encountered an upward current which lifted him almost a thousand feet, while Orville Wright, during the 1911 experiments at Kitty Hawk as already described, was supported in his glider on such a current for nearly ten minutes, sometimes stationary, again gliding forward or backward, and sometimes rising to a considerable height above the starting point. These various experiments are good indications of what may be expected when the possibilities long ago revealed by science are put to the test of adequate investigation.

Theory of Soaring. The fundamental postulates of the mechanical theory of passive flight are very simple. They are summed up by Lord Rayleigh in the following paragraph:

> I premise that if we know anything about mechanics, it is certain that a bird without working its wings can not, either in still air or in a uniform horizontal wind, maintain its level indefinitely. For a short time, such maintenance is possible at the expense of an initial velocity, but this must soon be exhausted. Whenever, therefore, a bird pursues its course for some time without working its wings, we must conclude, either (1) that the course is not horizontal, (2) that the wind is not horizontal, or (3) that the wind is not uniform.

Rayleigh's first postulate covers the case of volplaning, which is accomplished on a generally downward course. The second and third postulates comprise all cases of soaring ever yet adequately observed in art or nature. In our present state of science no other cases are admissible. Many observers, it is true, testify that a bird can soar in a uniform, horizontal wind or in a dead calm, which is its mechanical equivalent for that purpose, but such flight is beyond the power of aerodynamics to explain, if, indeed, it be not equivalent to perpetual motion.

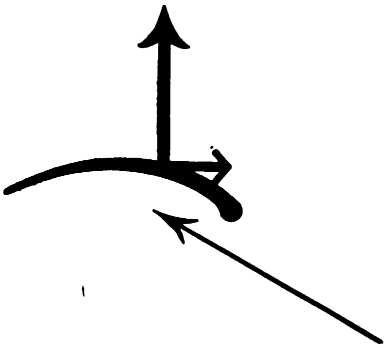


Fig. 27. Force Diagram for a Soaring Plane

Soaring, then, is possible only in ascending air or in a wind of variable velocity, by which is intended a wind that varies in speed, in direction, or in both. In other words, it is possible (1) in an ascending flow of air; (2) in a horizontal striated flow, in which the stream lines are all parallel but the velocity varies in neighboring striae or strata; (3) in a horizontal wind of fluctuating speed; (4) in a horizontal wind of fluctuating direction, either horizontal or vertical. The chief types of maneuver for such conditions may be considered briefly here, as also the prevalence of such conditions. Of course, this classification does not hold rigorously in nature, but may be assumed for the purpose of simplifying the analytical treatment.

Fig. 27 presents the well-known graphic analysis of soaring in an ascending current if the oblique arrow represents the relative wind and the other arrows the horizontal and vertical components of its pressure on the flier, it will hover still in space when the vertical component coincides with the weight and the horizontal component just neutralizes the head resistance. Obviously, also, the flier will advance or recede, rise or fall, according as these components of wind force prevail or are overpowered. If, further, the surface be tilted, it will have a third or lateral wind force tending to produce motion sidewise, so that the flier may glide to right and left across the wind, as well as in the other two rectangular directions. In an ascending wind, therefore, a passive flier can hover still, or advance in any direction. This form of flight has been practiced from time immemorial by all kinds of birds, even poor sailers, and is easily accomplished by any skilled aviator under favorable conditions.

Any skilled volplaner who wishes to practice soaring would, therefore, do well to follow the long-standing advice of mathematicians and choose a sandy slope up which the wind blows at any angle rather in excess of the flattest angle of descent possible in still air. The slope should preferably face the sea or a broad open stretch of level land. If, furthermore, the slope be wide, the aviator may soon learn not only to hover, to advance, and to recede, but also to patrol the entire slope to and fro laterally. As an instance of such procedure, Dr. A. F. Zahm, who is an authority on the subject and the author of the present synopsis of soaring flight, cites the fact of having seen a crow, which usually beats its wings continually in flight, soar to and fro on rigid pinions along a stone wall over which a stiff wind was blowing, and at times also rise and descend, advance and recede, then instantly take to violent beating when caught in the general current away from the wall.

Conditions for Continuous Soaring. Obviously, continuous soaring is possible on a rising current whose vertical component equals or exceeds the slowest possible rate of descent of the glider when coasting down still air. If, for example, a bird in calm air can glide at a speed of 20 miles an hour down a slope of one in ten, it can soar continuously in a current rising with a vertical component of 2 miles per hour; while an equally efficient flier moving 60 miles an hour would require, to maintain soaring, a current rising at no less than 6 miles per hour. From this it follows that the slowest and most amply surfaced gliders, like butterflies, require the least ascensional trend of air for soaring. Still, such fliers are far from being good soarers because of their incapacity to acquire sufficient speed and momentum to cleave swift winds and drive their way for a considerable time in spite of unfavorable conditions.

Ascending Winds. Ascending winds due mainly to uneven temperature distribution and to inequalities of terrene prevail very generally over the globe. Lilienthal concluded from instrumental observation that the general trend of the wind is three degrees upward. His was, of course, a local and empirical study. But on principle it may be qualitatively affirmed that the general course of the wind is slightly upward. The rising air is, on the average, warmer than the descending air; hence, its volumetric displacement is greater and consequently its general direction of flow is slightly upward. This effect is intensified where the air from a surface of water or vegetation passes over a barren or desert soil. Ascending vortices are very abundant, particularly over a heated terrene exposed to direct sunshine. Meteorology teaches that every isolated cumulus and thunder head marks the top of a rising column of hot air. All heated slopes, especially in the early part of the day, produce updrafts, particularly if they be long and barren. Precipitous islands and coastlands cause strong ascending currents which the sea birds know so well how to use. Over the desert, numerous columns of sand reveal the rising vortices continually. On torrid plains, large isolated trees have a powerful uprush of air above, initiated, doubtless, by the tree itself from the hot stratum of air beneath. Thus, the skilful soaring bird finds abundant elevators as he coasts about the atmosphere, which may be used to prolong his meandering glide till the next elevator is encountered, whether this be a vortex or an upwardly deflected wind.

Horizontal Winds. Soaring in a truly horizontal wind whose speed varies considerably at neighboring levels, or in different striæ at the same level, is easy to understand in theory. The bird, or flier, acquires sufficient speed in the swifter stratum to enable it to glide into the lower stratum, there reverse its direction and return in the teeth of the swifter current, to be again caught up and given a new impulse as before. Many instances of such flight are reported in nature, but none in human art. The theory has been presented by Lord Rayleigh in his "Mechanical Principles of Flight," by Vogt in "Engineering," and by various other writers, but the actual performance still challenges the skill and cunning of the practical aviator. The fact that the wind moves in neighboring strata and striæ is well established, but it is still to be proved quantitatively that the rate of change of speed is quite commonly sufficient to support prolonged passive flight.

Horizontal Winds of Pulsating Character. Soaring in a horizontal wind of pulsating speed has been qualitatively explained by Langley, and quantitatively studied by Chanute and others. The general theory conceives that the flier faces the direction of the wind, rises and drifts backward when the wind freshens, sinks and advances during the lull. This explanation is valid, provided the horizontal acceleration of the wind be sufficient. Langley, therefore, recorded the pulsations of wind speed by means of very light cup anemometers to obtain a physical basis for his theory. The records, Fig. 28, show quite remarkable fluctuations in speed, but not sufficient to maintain soaring in any flier of art or known nature up to the present. The total forward resistance of a well-formed aerial glider, or bird, may be taken as one-eighth its weight; hence, if poised stationary in its

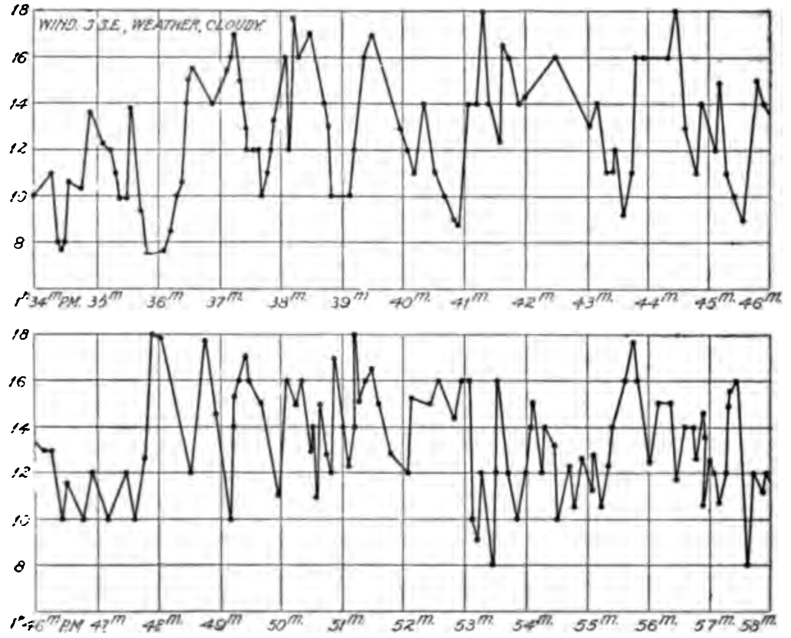


Fig. 28. Langley's Record of Speeds of a Pulsating Wind

normal attitude of flight, it will be just sustained by a direct head wind having a horizontal acceleration of one-eighth that of gravity, or four feet per second. This is obviously true of all gliders, whether swift or slow, whose total resistance equals one-eighth of their weight. Now, the most favorable parts of the record here shown nowhere exhibit an acceleration so great as four feet per second and, on the average, show far less than that, as may be seen by scaling the diagram. Hence, the wind here recorded was wholly inadequate to support, by its pulsative force, either bird or man. As this record is a fair representative of all those published by Langley, it follows that at best such pulsations can merely aid in soaring when happily and adroitly encountered; but that they can not fully sustain soaring at any level, much less during ascensional flight to great altitudes, or migrational flight over vast distances. This conclusion is applicable even to those gliders which are reported to require a propulsive force of but one-fifteenth, or one-twentieth of their total weight. Hence to account for soaring in a horizontal wind of fluctuating speed, it seems necessary to postulate a pulsating breeze of far greater acceleration than those recorded by Langley in his paper on "Internal Work of the Wind." Fuller and more varied records of the pulsations in the wind's velocity may be found in the Interim Report for 1909 of the British Advisory Committee for Aeronautics.

In a horizontal wind that pulsates in direction merely from side to side, soaring may be aided by the alternate impulses of the air against the flier, resisted by its inertia. If the wind freshen well from the right quarter and the flier lists to port, it will be driven to port; then if the wind blow promptly from the left quarter, while the flier is tilted to starboard, it will have its acquired component of momentum to port reversed and will drift to the right. In each case, the oblique lift on the wings may have a component generally forward, tending to overcome the entire head resistance. The magnitude of this forward component of the normal pressure on the tilted flier is easily seen to be, at any instant, equal to the product of such normal force multiplied by the sine of the angle of the tilt and by the sine of the angle between the quartering wind and the forward course. If, for example, each of these angles be 30 degrees at any instant, the propulsive force is one-fourth of the whole normal component, which, of course, would be ample to overcome all resistance.

Continuous soaring in such a laterally pulsating current would, however, require phenomenally wide and rapid fluctuations of wind direction, and great alertness on the part of the flier. The case is worth notice as showing that a glider can receive both support and propulsion from a quartering wind, and can even tack successfully, like a ship, if the horizontal fluctuations in direction be suitable. In a generally horizontal wind that undulates up and down, soaring may be aided in various ways, if not continuously sustained. If the aerial vibrations be strong and rapid, as in a fluttering wind, they may exert a sculling action on the wing as a whole, or on its flexible rear margin. In such case, the narrow flexible wing of the bird would be more effective than the broad stiff wing of an ordinary aeroplane, though, of course, narrow and pliable pinions can be used in aeroplanes and gliders to adapt them to soaring in fluttering winds. Such sculling action may occur in wind undulations of considerable period and amplitude, as where the air follows the contour of the billows in a heaving or tempestuous sea, particularly if the flier glide across the undulations at considerable speed, like the albatross, thus greatly increasing the apparent frequency of the rise and fall of the air.

Mouillard likens soaring in such heaving air to the motion of a marble on a wavy groove in a vertical plane, which a skilled hand moves up and down in such opportune manner as to cause the marble to ascend rapidly on a long wavy slope. The comparison is a good one, except for the fact that gliding on the yielding air is less efficient than sliding or rolling on a rigid track. But if the potential energy can be rapidly acquired on the Mouillard track, perhaps also on the aerial track, increased altitude can be attained under favorable circumstances, Dr. Zahm citing a case where he has caused a model glider to ascend on a wavy course in the air by pulling vertically down on it intermittently with a thread. Such gliding appears to represent a fairly accurate approximation of soaring in a wind oscillating rapidly in a vertical plane.

In case the undulations of the air be due to a vortex rolling about a horizontal axis while advancing with the wind, as supposed by some writers, the bird or glider might remain on the ascending side of the vortex and thus obtain continuous support while advancing with the speed of the rolling vortex, whether fast or slow. Such a performance might seem marvelous or paradoxical to the witness, since the rolling vortex must be quite invisible, but the feat would be no more remarkable than some reported by aviation experts who claim to have witnessed the passive flight of aquatic birds for thousands of feet just over the surface of still water in a hardly perceptible breeze. The rolling vortex of Chanute and Herring offers fascinating possibilities. The aviator need only saddle his glider deftly on this transparent Pegasus to go kiting over all creation. But the fine art is to locate and lasso such a wild-wind horse.

Fig. 29 exhibits typical records of the changes in wind direction, both horizontal and vertical, obtained by Dr. Zahm by means of a special recording wind vane exposed in a clear open space of 200 acres, and in a wind of eight to twelve miles an hour. The diagram shows that the wind veered quite frequently 10 degrees in a short interval of time, and not infrequently 20 to 30 degrees. In strong winds the fluctuations of both velocity and direction are generally more marked than in moderate winds, as has often been observed in meteorological records. Hence, they furnish a good physical basis for the belief that soaring may be materially aided, if not continuously sustained, by pulsating winds.

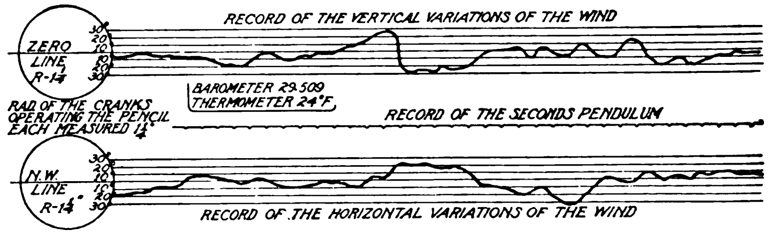


Fig. 29. Curves Showing Changes in Horizontal and Vertical Wind Directions Recorded by Zahm

Aspiration. According to Carl E. Myers, the solution of soaring flight is dependent upon the phenomena of "aspiration." Given an undulatory wind power whose flowing stream of waves is split apart by the edge of an intervening surface having weight below to prevent it from capsizing, and whose rearward surface curves slightly downward, so as to divert the undulating waves slightly downward and to inspire an uplift in the aeroplane, and we have the phenomena of aspiration, as a result of this "internal work of the wind," as Langley termed it. Among the examples of this power of the wind, Myers cites the case of the ball floating above the surface of a flat table, and the automaton representing a magician balancing a ball in air above a wand and transferring it from this wand to another held in the other hand. In one case the ball simply danced on an invisible jet of air rising under considerable pressure out of an inconspicuous hole in the center of the table, while in the other, the ball was controlled by jets of air alternately issuing first from one wand and then from the other. What appeared to be magic of a high order was simply wind. Another instance was that of the captive balloon operated by Myers from the government reservation of the Navesink Twin Lights, at Highland, New Jersey, for observation and the reporting of the yacht races for America's cup some years ago. As this balloon ascended about 1,000 feet above the brow of the hill, it was pushed over and down the steep hill by the rush of wind which came across the upper flat and poured down the slope to the sea like an invisible aerial Niagara. Thus there was the novel exhibit of a fully inflated gas balloon with its passenger captive at the end of a rope which was anchored to the hilltop, forced down below and brought near the sea level by the plunging overflow of the wind. On days when the wind blew off the sea and uphill, the balloon ascended with it, even when half full and otherwise unable to lift itself and its passenger, just like a great parachute or umbrella when the wind indented the under or slack side. It was merely a gas kite and a man-sized kite would have done as well. Wind and surface did the lifting and it soared and hovered. As the result of this experience, Myers undertook a series of experiments from which he evolved the theory of "undulatory flight." Any undulatory movements of surfaces will produce undulatory movements of air and, conversely, undulatory progressive movements or waves of air impart force or motion transversely to the line of flow. Thus a flag wriggles in the wind, wasting its power in flaps. The experiments were carried out by means of kites and resulted in the evolution of the "Texas Self-Flying Kite," of which Myers supplied one hundred to the United States government for the artificial rain-fall experiments carried out in Texas in 1891. The kites were employed for firing charges of dynamite at great altitudes. Chanute considered this "a very interesting example of partial aspiration" and devotes a number of pages in "Progress of Flying Machines" to the spectacle of the flight of these kites, three miles up in the air, and their disappearance rising higher, ten miles distant. From this Chanute came to the conclusion that "*inanimate surfaces cunningly balanced and continually balanced could fly.*" The veteran engineer Lancaster reached the same conclusion many years previous, as in an address to the meeting of the Associated Civil Engineers at Buffalo thirty years ago, he declared that he had repeatedly built "effigies" which arose from his hand and mounted into mid-air out of sight—a statement which aroused so much derision as to practically drive him into exile. In support of his claims, Lancaster carried out extensive observations of birds, and relates that, on one occasion, concealed in a canvas covering painted to represent a dead tree top, he has watched a large bird, the gannet, poised within reach in mid-air with its eyes closed, balanced, motionless with only an occasional slight ruffling of its plumage. When touched with a pole, its eyes opened, and, disconcerted, it slid back a few feet, then regained its former position and repose.

A bird's wing is a complex combination of curved, stiff, and elastic surfaces—the curves and stiffness being greatest forward, and the flexibility and capacity for separation being greatest aft, or in the line of undulatory air flow. Wings move or operate upon fixed pivots, at any angle or inclination, controllable by will or power, and also automatically by wind or gravity. The wind never flows "straight along" and in its general direction it never ceases to vibrate, oscillate, or undulate in all ways or directions, as an elastic flowing stream, acting forcibly upon any suitably arranged and adapted surfaces, to urge the complex whole forward or buoy it up, with no power lost save through friction. The bird is a balanced, pendulous weight, wholly and in parts. His vital functions render his flying features less competent than an inanimate structure of equal flying power may be. Myers states this not as the problem, but as its solution, and adds that "*any apparatus fairly conforming to the conditions will fly or float in due proportion to its structure.*"

MODERN AERODYNAMIC RESEARCH

There is yet so much to be learned regarding atmospheric laws and their influence upon flight, that well-equipped experimental laboratories are indispensably necessary to the further progress of aviation. Just as the initial success of the Wright Brothers was the culmination of years of scientific research which demonstrated the worthlessness of many theories that for years previous had been regarded as well established, so the development of the future will be the result of consistently carried out lines of investigation, rather than the outcome of chance discovery. The practical use of the aeroplane in the hands of such a large and rapidly-increasing number of aviators will undoubtedly lead to improvement in construction and design, but for that thorough knowledge of the principles which is essential to increased efficiency and finality in design, we must look to the scientist and his laboratory.

Aerodynamic Institute of Kutchino. It is somewhat of an anomaly that the most important and best-equipped laboratory should be found in a country which has done least for the progress of aviation, that is, the Aerodynamic Institute of Kutchino, near Moscow, Russia. This was established several years ago by a wealthy scientist, M. Riabouchinsky, and is maintained by its founder.

Propeller Experiments. One of the first researches attempted was a study of air resistance, an artificial and easily controlled current of air being produced in a tunnel for this purpose. This tunnel is horizontal, 48 feet long by 4 feet in diameter, and is equipped with an electric fan 39 inches in diameter to draw air through it, as it was found that the current produced by aspiration was more uniform than that set up by forcing air into the tunnel. The models to be tested are placed inside the tunnel, which is equipped with conveniently-placed windows for observation. The small Caselli anemometers are suspended within the tunnel by light steel wires, one fixed at the axis, the other movable. The indications of the former are found to be always directly proportional to the speed of the electric fan. The wall and floor of the room were found to affect the regularity of the air current when the tunnel was open, so that it was covered with a light metal grating, but this did not prove satisfactory and it was replaced by a series of screens between the end of the tunnel and the wall without attaining the result desired. Finally, a cylindrical cap about 7 feet in diameter by 11 feet long into which the end of the tunnel penetrates 6 feet, was adopted. This cap is made of wood and is lined with coarse cotton stuff, while the tunnel itself is of sheet steel. From this excellent results are obtained, the mean difference between the greatest and lowest velocities in the tunnel being approximately $\frac{8}{10}$ inch per second. The tunnel is employed for various researches, including a study of the movement of air propellers in a current. Maxim observed that when the wind blows at right angles to the axis of a propeller, its propulsive force is increased, and this has been verified by Professor Joukovsky in experiments made to determine the variations in the lifting power and the work performed by the screw, in relation to the velocity of a current at right angles to its axis.

These experiments were carried out as follows: A two-bladed propeller 12 inches in diameter with its blades inclined 6 degrees, is driven by an electric motor *A*, Fig. 30, attached to a steel frame inserted in the tunnel. This frame can turn freely about a horizontal axis at *B*, while the other end is terminated by a rod *C*, passing through the wall of the tube. To this rod is attached a cord passing over a pulley *E*, and supporting a scale pan *F*. By placing weights in this pan, the frame can be balanced with the screw at rest or in motion. The difference between the weights in the two cases, multiplied by the ratio between the arms of the lever *BD* and *BA*, gives the lifting power of the propeller tested. The work performed by the propeller is ascertained by Colonel Renard's method. The motor is mounted on pivots so that it may turn freely. To the motor is attached a ring *G*, about 2 inches in diameter, over which passes a cord, traversing the wall of the tunnel, passing over the pulley *H*, and terminating in the scale pan *F'*. By the effect of the reaction, the motor is impelled to rotate in a direction opposite to that of the propeller. The moment of the force turning the motor, which is equal to that of the force turning the propeller, is obtained by multiplying the weight (added to that of the scale pan *F'* during the rotation of the propeller) by the radius of the ring surrounding the motor, and the work performed is obtained by multi-

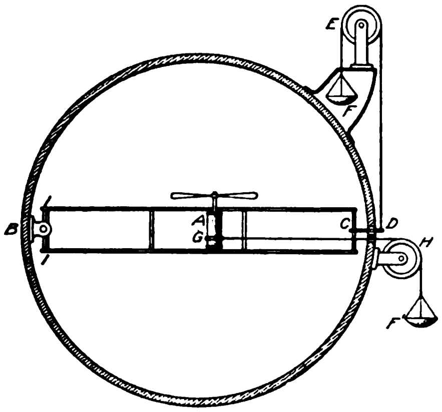


Fig. 30. Air Propeller Revolving in Air Current Perpendicular to Its Axis

plying this moment by twice the number of turns per second made by the propeller. These experiments show that the lifting force of the propeller, as well as of the ratio between this force and the energy expended, increases with the velocity of a current of air at right angles to the axis.

The most important researches made at the Kutchino laboratory naturally relate to propeller design. Riabouchinsky classifies sustaining apparatus in four groups: (1) The car group, including ordinary cars, aerial-paddle wheels, and apparatus comprising wings with valves. (2) The screw propeller group, including the screw, the aeroplane (which is regarded as the blade of a propeller of infinite diameter), and apparatus with wings vibrating in a plane perpendicular to the direction of the thrust. The action of all apparatus in this group is based upon the properties of the inclined plane.

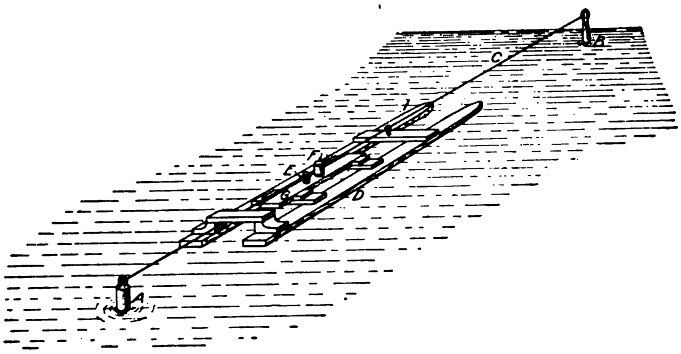


Fig. 31. Apparatus for Studying the Impact of a Current on a Surface

(3) The centrifugal pump group, comprising apparatus in which air attracted by the barometric depression formed at the center is projected outward by centrifugal force and then diverted in the proper direction by fixed surfaces. (4) The weather vane group. The operation of apparatus of this class is illustrated by experiments with an elongated rectangle in rotation about an axis at right angles to the direction of the air current. In regard to the study of the inclined plane, Lilienthal pointed out that the specific resistance experienced by each element of a sustainer with wings may be twenty times as great as that of a plane moving uniformly in a straight line. He attributed this increase of pressure to the inertia

of the surrounding air. Joukovsky explains the increase by the formation of air waves through the vibration of the wings. Goupil also has observed that the mean pressure per unit of surface in the case of an alternating and accelerated rotary motion is greater than in uniform motion in a straight line. He accounts for the increase, partly by the inertia of masses of air clinging to the surfaces and partly by the increase of the relative velocity of the current which meets each element of the surface in consequence of the centrifugal acceleration.

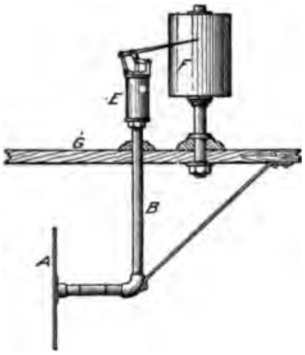


Fig. 32. Details of the Recording Part of Fig. 31

Riabouchinsky began by studying a sustainer, the blades of which had an alternating rectilinear motion and subsequently determined the specific resistance for uniform circular motion. In the latter case, he finds the coefficient of resistance equal to 0.885. For the purpose of studying the effect of the impact of a current upon a surface he devised the apparatus shown in Fig. 31, composed of two planks *DD*, connected by cross ties and forming a sort of raft, which can descend the current of a stream, guided by the wire *C*. Upon the raft is mounted the apparatus shown in the enlarged detail illustration of Fig. 32, consisting of a tube *B*, 6 inches in diameter, with an indicator *E*, registering the pressure in the tube upon the chronograph cylinder *F*. *B* is L-shaped, its horizontal member containing a piston rigidly attached to an aluminum disk *H*, 12 inches in diameter and $\frac{1}{12}$ inch thick. The tube *B* is filled with water and the board *G* upon which it rests is capable of sliding with some friction in grooves cut in the cross ties, Fig. 31. The post *A* allows the raft to pass, but suddenly stops the board *G*, the pressure thus produced being recorded on the chronograph cylinder.

To determine the components of the pressure of an air current upon an inclined plane, the apparatus shown in Fig. 33 is employed. The vertical axis *A* turns in ball bearings *CC*, and can be fixed in any position in the tube *B* by the screw *P*. A plane surface *E* is attached to the lower end of the rod, while the upper one carries a counterpoise *T* and an index *I*. To the tube is fitted a copper circle

Q, 24 inches in diameter and divided into degrees. The tube swings on the pivots *GG* and is brought back to the vertical by means of a beam and scale pans. By placing the required weight in the pans, the pressure exerted upon the plane can be balanced and measured. By turning the axis *A* in the tube, the plate *E* can be caused to meet the current at different angles, and the components of the pressure for any given inclination can be obtained by turning the graduated circle *M*. Furthermore, by fixing the beam of the balance and unscrewing *P*, the position of the center of pressure can be determined, if the plate *E* is replaced by a plate capable of turning about the points *CC*, as shown in the small illustration at the right, Fig. 33. It is found that the displacement of the center of pressure as a function of the angle of incidence depends not only upon the distribution of pressure on the front of the plane, but to a still greater degree upon the reduction of pressure at the back. This reduction is greatest near the forward edge.

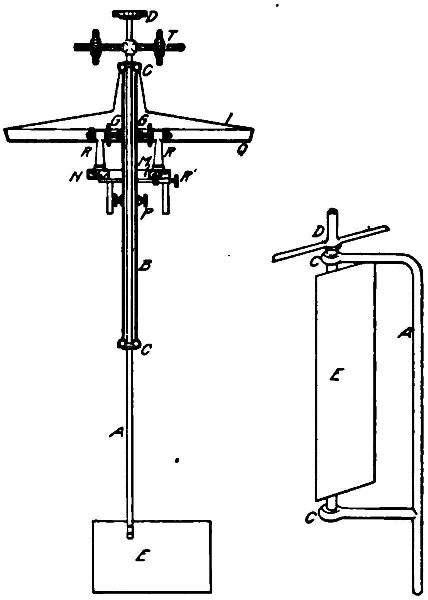


Fig. 33. Apparatus for Measuring Components of Pressure on Inclined Plane

Lifting propellers, such as are employed in helicopters, have been studied with the aid of three types of apparatus. One of these is a modification of Renard's double dynamometric balance, from which it differs only in having the propeller placed some 6 feet above the motor, so that it operates in a perfectly clear space. In order to measure with precision the moment of resistance, the propeller must be arranged to drive the air backward. The angular velocity is measured by means of a seconds clock, which is started and stopped by an electromagnet after each one hundred revolutions of the propeller. The propeller and motor are suspended by means of cords upon two pairs of knife-edges, of which one is parallel and the other perpendicular to the axis of the propeller. This balance serves for testing propellers of from 20 inches to 10 feet in diameter.

The second apparatus, Fig. 34, is for the purpose of testing model propellers, measuring from 8 to 20 inches in diameter, by determining separately their thrust and moment of resistance. In this apparatus the axis of the motor *M* is vertical, and its extension (the shaft *CC*) ends in a bevel gear transmission *D* by which the propeller *H* is driven. The vertical shaft *C* is free to rise, sink, and revolve, and its weight and that of the motor, etc., is counterbalanced by the pan and pulley system *KY*. The whole mechanism is pivoted on the knife-edge *A*, so that when the propeller is revolving, its thrust may be measured by a spring dynamometer, the deflection being indicated by the pointer at the top. With this apparatus very interesting researches have been made, the results being published in a series of bulletins issued by the Institute.

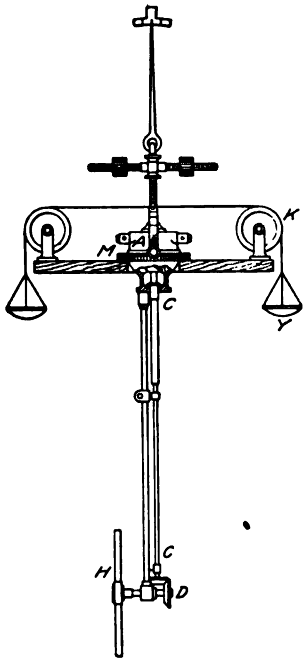


Fig. 34. Apparatus for Testing Model Propellers

The frictional resistance of the air to the motion of a surface is studied with the aid of an apparatus consisting of an endless band of rubber, covered on both sides with cloth and stretched over two hollow cylinders 20 inches in diameter, the band itself being about 5 feet wide. One of the cylinders is turned by a 14-horse-power electric motor. Between the two cylinders and between the upper and lower halves of the traveling band is a smooth horizontal table 40 feet long by 6 feet wide.

Eiffel Aerodynamometric Laboratory. Gustave Eiffel, the builder of the well-known Eiffel Tower at Paris, has carried out a long series of experiments of considerable value, and the Eiffel Aerodynamometric Laboratory is probably the most important in France, where aviation long since reached the status of an industry.

Wind Pressure Experiments. M. Eiffel undertook to procure accurate data concerning wind pressures, in 1903. From the first platform

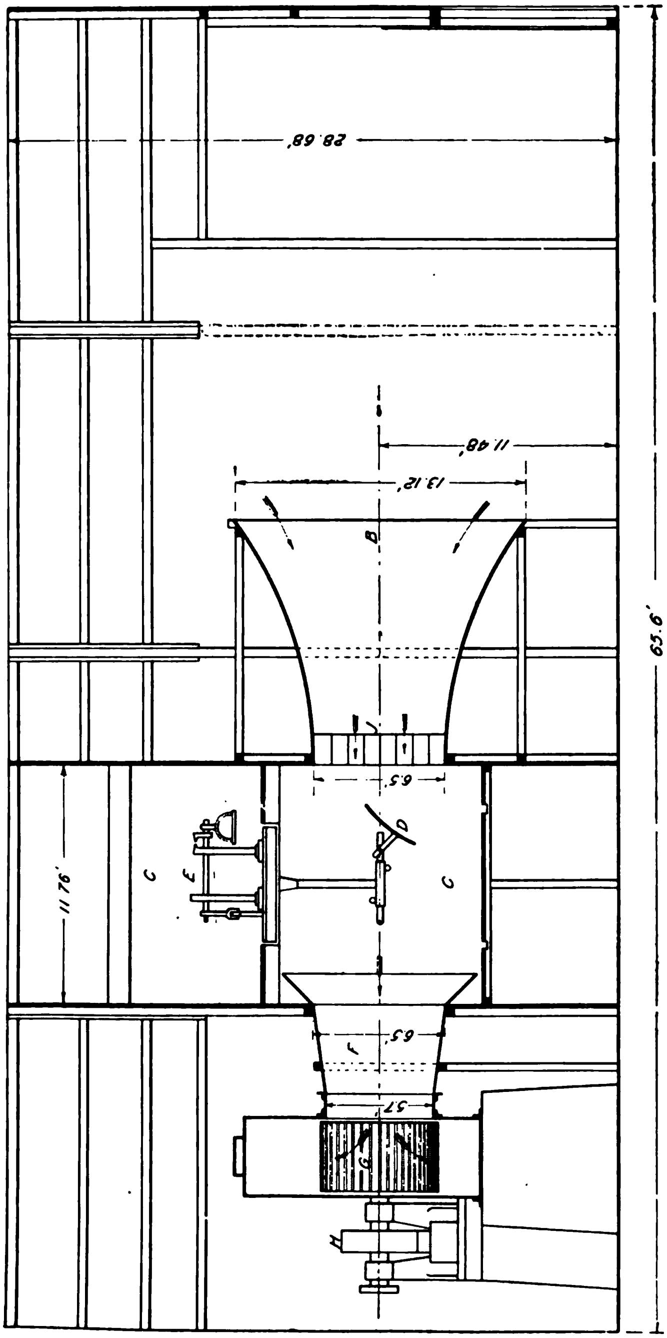


Fig. 35. Longitudinal Section Eiffel Aerodynamometric Installation

of the tower was suspended a steel cable, increasing in diameter as it approached the bottom. A device, designed to be dropped along this cable, was carried on a frame with two powerful vertical leaf springs fixed to the halves of two sleeves, placing the latter under considerable pressure. Wood liners were inserted in the sleeves so that when the apparatus reached the cylindrical part of the cable, the conical section spread the sleeves against the pressure of the springs, which exerted an effective braking effort. The frame carries a recording drum rotated by a worm shaft actuated by a friction roller on the cable. The plane to be tested was fixed to the lower part of a stem free to move upward against a spring, the upper part of the stem carrying a needle which bore against the drum. This heavy apparatus dropped from a height of 377 feet, and during 311 feet of its course, before the braking action began, it attained a velocity of 131 feet per second.

The air resistance expanded the accurately calibrated spring, causing the registering needle to rise on the drum, which rotated at a speed proportionate to the velocity of the drop, recording the air resistance for every point of the descent. This method naturally had its limitations, because it was possible to ascertain only the total resistance offered to a plane when falling at a given velocity. Much interesting data was obtained, but the possibilities of the apparatus were soon exhausted. It is generally conceded that more practical results are obtainable by moving the surface to be tested through the air, thus securing conditions more closely approaching the normal, but there are so many difficulties in the way of extending this line of research and making accurate observations, that Eiffel found it necessary to follow the lead of Maxim and other experimenters by employing stationary surfaces in a current of air.

In order to obtain accurate data in this manner, the plane must be in a cylinder of air of sufficient diameter to avoid influencing the outer stream lines by its pressure. The surface tested must not be too small and it was found that the diameter of the air current should not be less than 5 feet. The installation, which has been in use for some time, is located in a building adjoining the Eiffel Tower and is shown in section in Fig. 35. It consists of a Sirocco ventilator 11 feet in diameter, and a fan *G*, 5 feet 9 inches in diameter, which, with its masonry setting, has a total height of 18 feet. The ventilator is driven by a 70-horse-power electric motor *H*, at a speed of 40 to 200 r.p.m., by means of which the velocity of a cylinder of air 5 feet in diameter may be varied from 16 to 65 feet per second. The air receiver or collector *B* is built up of a wood frame covered with rubber balloon fabric; its largest diameter is 10 feet or just double the aperture, and its length is about 8 feet. The object of this collector is to provide a slight compression of the air, so as to favor the regularity of the stream lines. However, if the air were drawn through an unobstructed aperture, the horizontal column would be broken up into a mass of whirls, so that to obtain perfectly parallel stream lines, the opening is fitted with a grid *J*, which is shown in Fig. 36, built up of thin sheet metal similar to a honeycomb

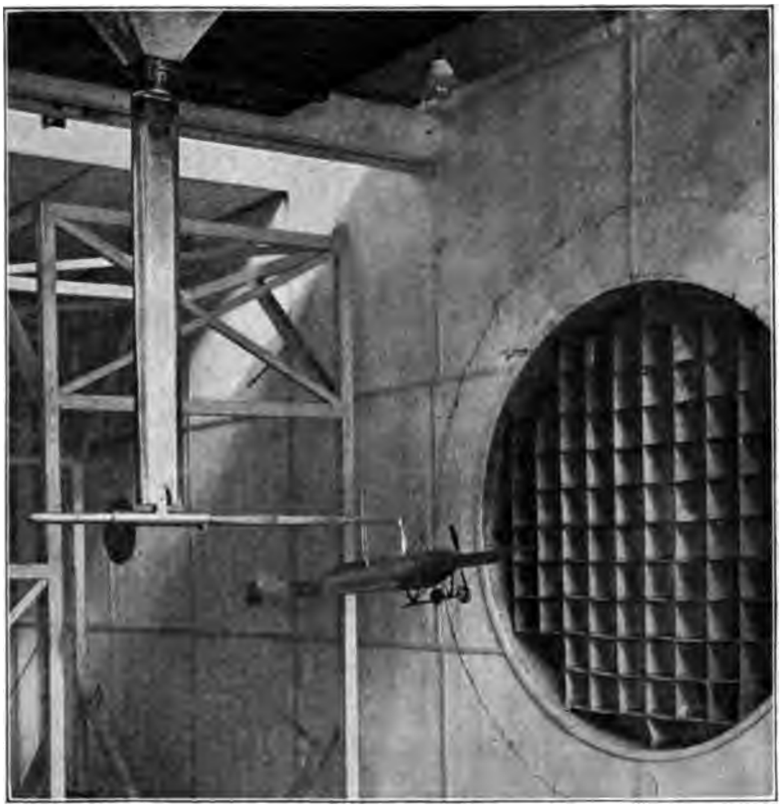


Fig. 36. Method of Testing Models of the Eiffel Aerodynamometric Laboratory

automobile radiator, each cell being 4 inches square by 10 inches long. These dimensions were not based upon any settled data, but were first adopted experimentally and retained after proving satisfactory in operation. Opposite this grid is the short cone *F*, Fig. 35, around the opening of the tunnel, at the end of which is placed the ventilator, the distance between the two apertures being 11 feet 9 inches. It was noticed at first that the air broke up into whirls immediately in front of the aperture so that it was covered with a wire netting having a mesh of .39 inch, another wire netting being placed about 3 feet in the tunnel. With this arrangement, the air current is so perfectly cylindrical that when traveling at the highest velocity there is not the slightest draft in the experimental room.

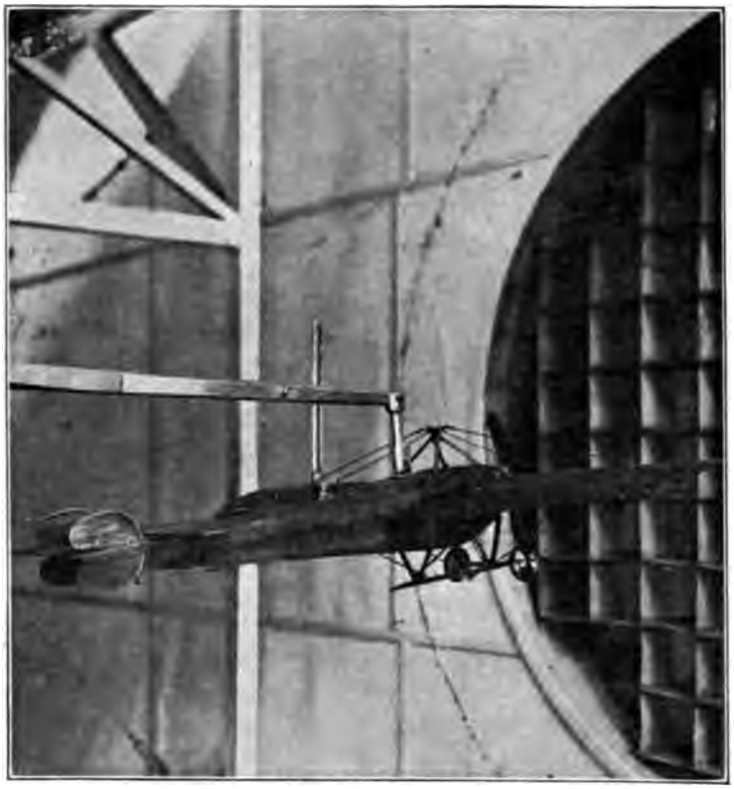


Fig. 37. Detailed View of Monoplane Model under Test at the Eiffel Laboratory

This room *CC* is in the shape of a T with one part parallel to the side of the building. It contains a table with the recording instruments and a switchboard. The weighing machine *E* for measuring the wind pressure is on a platform suspended from an upper story. The plane *D* to be tested is attached at its center to a piece hinging on the end of a horizontal rod, Fig. 36, and is also attached to a sliding piece, shown in detail in Fig. 37, capable of being fixed by a set screw a few inches along the rod, so that the plane can be turned round 180 degrees and fixed in any position. The horizontal rod is clamped in a sleeve at the bottom of a vertical, cast-steel rod contained in a copper casing of larger diameter, and presenting a beveled edge in the axis of the stream lines, so as to offer the minimum resistance. The vertical rod is bolted to the platform of the weighing machine, which is carried on two sets of knife-edges, one set turned downward and the other upward. This is necessary for measuring the pressure when the plane is inclined up or down. The platform is made to rest on one or the other of the knife-edges by shortening or lengthening the rod from the platform to the cross beam by means of a cam, and when not in use the platform is raised to bring the knife-edges out of contact with the grooves by a lever with a counterweight. This weighing machine, which was constructed especially for the installation, is sensitive to half a gramme.

In testing a plane, the equilibrium is obtained by weighting the balance with the knife-edges alternately in their grooves, before the air current is passed through the experimental room. The latter is then traversed by a current of given velocity, determined by the speed of the ventilator, as regulated by the rheostat. This velocity is gauged by a manometer communicating between the air current and the still air of the outer shed, and also by a Pitot tube placed in the current and connected with a manometer which also communicates with the still air. Results are further verified by various anemometers and the differences between the two are so small as to be inappreciable from the viewpoint of general results.

Having ascertained the air velocity, the balance is again weighted with the knife-edges in contact, first on one side and then on the other, and the plane is then turned 180 degrees, when the equilibrium is effected on the corresponding edges. These operations provide three equations for determining the total pressure, the direction, and the center of pressure. Another method of determining the center of pressure consists in placing the plane vertically between the points of two rods, the ends of the plane being drilled so that it may be held in any position. The plane is secured by a clip on the lower rod, to which is fixed a circular plate of wood with the angles marked on the edge and corresponding with marks on the fixed frame. When exposed to the air current, the plane pivots round more or less, according to its curvature, and the angle is read off to give its center of pressure. This method might be expected to lack precision, but the results agree with those provided by the weighing machine.

For ascertaining the wind pressure at different parts of the plane, the instruments employed are a Pitot tube and a Schultze micromanometer, and it is mounted on a frame sliding on rails to allow of its being brought in front of the aperture. Any desired inclination is obtained by means of wires, and the plane itself is drilled with a number of holes which are filled with screws flush with the surface. At the point where it is desired to ascertain the pressure, the screw is removed and replaced by a threaded plug. On the side subjected to the wind pressure the plug is flush with the surface, while on the other side it carries a rubber tube connected with the micromanometer. The pressure can thus be obtained at any point on either side of the plane. Highly interesting data have been obtained with this apparatus, and as evidence of the accuracy of the method it may be mentioned that the sum of the pressures obtained over the surface corresponds exactly with the total given by the weight bridge. It is thus possible to obtain the center of pressure, the total pressure, and the pressure at any given point on either side of the plane. Another valuable factor is the disturbance of the stream lines caused by the presence of the plane. This is ascertained by attaching light filaments to the plane or to fine wires, and by observing their movements it is possible to sketch plans of the air whirls around and behind the plane.

It is sometimes argued that experiments with a fixed surface in a current of air have little practical value for purposes of aviation, for the reason that these conditions are contrary to those governing the flight of aeroplanes. The experiments are carried out under one of many conditions, and this one is met with only when the aeroplane is at a standstill against the wind. It is obvious, however, that this one condition constitutes the basic principle of flight, and no other factor can be introduced beyond providing devices for giving stability to the machines. Confirmation of this is to be found in the fact that the Eiffel tests have demonstrated that the best compromise between lift and resistance lies in a flattened curve similar to that adopted by certain aeroplane makers after years of costly experimenting.

Results of Research in Various Laboratories. It will be apparent from the foregoing that it is the precise methods of the scientist that will eventually place flying on a successful commercial basis. As in all other branches of engineering, the theorists and the physicists point the way that leads the practical man to the definite solution of perplexing problems, and in this aviation differs in no respect from any other art or science. The determination of the fundamental characteristics of air flow and air pressure on different kinds of surfaces and forms has led without doubt to a quicker and surer success in actual aeroplane flight, but it is qualitative rather than quantitative results that have been obtained so far. Up to the present, few if any experiments in measuring the actual values of pressures on surfaces have been conducted on full-sized aeroplanes. The results that have been obtained come chiefly from extensive indoor laboratory experiments conducted on planes and shapes of small size, often only one-thousandth the size of the planes used on successful machines, as detailed in connection with the investigations of the Kutchino and Eiffel laboratories just described. But these small-scale experiments in most cases have been performed with great care and refinement, and from their results there have been established the following empirical and fundamentally important laws and equations:

(1) The air pressure on any plane or shape varies, within the range of speed used in flight, substantially as the square of the velocity and directly as the size of the surface. For the simplest case—a flat plane placed normal to the air stream—the air pressure P may be expressed as

$$P=KAV^2$$

where A is the surface area, V the velocity of the moving air against the fixed surface, or conversely, of the moving surface against still air, and A a numerical constant or coefficient, the mean value of which may be taken as .003 when A is expressed in square feet and V in miles per hour. The methods employed in finding this and the various values given it by different investigators are described on pages 33–35. This is an empirical relation, derived from the results of the numerous experiments in question, and upon it is based practically all of the theory of aerodynamics that finds application in actual practice.

(2) Air passing a surface, or conversely, a surface moving through air, causes a frictional drag on the surface which varies almost as the square of the velocity and directly as the length of the surface.

Many formulas have been proposed, some based on experimental data and some on theoretical conclusions, but they differ widely from one another, and the value of this skin friction is still a subject of controversy, many experts claiming that it is negligible; many others that it is of considerable value. Here is a branch of aerodynamics still open to investigation, although the excellent results of Professor Zahm's experiments seem almost conclusive evidence of the large value of frictional resistance.

(3) The pressure on an inclined flat plane varies with the angle of inclination to the air stream but bears a fixed relation to the pressure on the same plane, when placed normal to the air stream. If it be assumed that P is normal pressure and P_1 is pressure acting on a plane when it is inclined below normal, at an angle a above the horizontal, then this fixed relation between P and P_1 may be expressed as

$$P_1 = P \frac{2 \sin a}{1 + \sin^2 a}$$

This is known as *Duchemin's formula*, and has been verified again and again by actual laboratory experiments on small flat planes, the Wright Brothers stating that after having attempted to verify all of the old formulas they found in existence at the time of beginning their experiments, their investigations showed that this was practically the only one of its kind of any value. A very simple approximate relation suggested by Eiffel is $P = P\frac{a}{30}$. The normal pressure P may be determined for any plane at any velocity by the relation of $P = KAV^2$, this pressure being gradually reduced as the plane is inclined to a value P_1, corresponding to that angle of inclination.

(4) The pressure on arched planes is much greater than on flat planes, and may be equated to the value of the pressure on a flat plane of larger area. Whereas in inclined flat planes the pressure P_1 is always perpendicular to the plane, on inclined curved planes at low angles P_1 is inclined in front of the perpendicular to the chord of the plane. Unlike flat planes, the pressure on curved planes can not be reduced to an intelligible formula and, therefore, in order to determine the pressure on curved planes, resort must be had to tables of air pressures obtained from tables of actual measurements on test surfaces and not to any formulas based on such measurements. The pressure P_1 on curved planes is usually tabulated as some percentage of the normal pressure P. It is in the determination of the pressures on curved surfaces that the results of aerodynamical experiments on small surfaces have been of the greatest value in aeroplane design. Lilienthal, Wright, Prandtl, Eiffel, Maxim, and Stanton have all made determinations for curved planes that have found wide practical application.

(5) On curved planes, as well as on flat planes, the total pressure P_1, acting on the plane when the latter is inclined at an angle a may be resolved into a vertical component L and a horizontal component D. The component L is termed the lift and is equal to the weight of the aeroplane, while D is termed the drift and is the dynamic resistance to motion overcome by the thrust of the propeller.

(6) On curved planes, as the depth or amount of curvature or arching is increased, the drift resistance increases. In other words, flatter planes have less resistance than more highly arched surfaces, this being illustrated by the use of very flat planes in high-speed machines. The experimental results of Professor Prandtl of Göttingen are particularly definite on this point.

(7) On curved planes, as the aspect ratio, or ratio of span of plane to chord, is increased, the lift increases greatly for the same area. Both Eiffel and Prandtl have amply verified this, and it is one of the most essential points of successful aeroplane design.

(8) Experiments show that on a plane there exists a point at which all the pressures on the plane may be considered as concentrated without disturbing the equilibrium. This center of action of

the forces is termed the "center of pressure." On flat planes, the center of pressure moves steadily forward from the center of the plane to a point near the front edge, as the plane is inclined from the normal or 90-degree position to zero, or horizontal. On curved planes a totally different action is observed. The center of pressure moves steadily forward from the center of figure to a point about one-third the width of the plane from the front edge, as the inclination is reduced from 90 degrees to 15 degrees, but at this point it turns abruptly and moves rapidly to the rear, passing the center of figure at about 5 degrees.

(9) Experiments in aerodynamic laboratories have further enabled forms of least resistance to motion to be determined, and show what kind of torpedo or fusiform shapes give the least disturbance of the air streams.

(10) Experiments on propellers have added immensely to the knowledge of this branch of aerodynamics, and have enabled air propellers to be designed that give a higher efficiency than is obtained in marine practice. The French propeller manufacturing companies have had extensive and elaborate experiments conducted with full-size propellers and have used the results to great advantage.

(11) The experimental photographing of the action of air streams on different planes and shapes has been a valuable contribution to aerodynamics and holds promise of becoming a field of much larger results within the next few years.

The foregoing are the fundamental qualitative results. In many cases, the values of different experimenters for the same thing show wide variations. In determinations of the constant K, for example, as already referred to in detail, various widely-differing values have been obtained, and many other differences are found. The quantitative results of experiments in aerodynamics are as yet not fixed, and it must be conceded that until reliable numerical values are obtained, the precise engineering design that is looked forward to is hardly possible, even though excellent approximations may be made.

Methods of Experimenting on Test Surfaces. The chief sources of error or difference in the experiments conducted thus far appear to be in the methods of conducting the experiments and the size of the planes used. Whether size of surface has any effect on the nature of the pressures or their unit values is a problem in aerodynamics that is still to be solved. Many claim that the majority of experiments have been conducted on such small test surfaces that their results are of little value. Like all other aerodynamical problems, the answer is to be found in experiment only. There are five different methods of conducting experiments on test surfaces or models. These are:

(1) Dropping the surface from a height in open air or a closed room, as already described in connection with the work of the Eiffel and Kutchino laboratories.

(2) Attaching the surface to a carriage moved on rails, as done by Professor Prandtl at Frankfort; or sliding down a long inclined railway, as performed by Signor Canovetti in Italy.

(3) Mounting the surface and testing apparatus on an automobile and driving at high speeds, taking careful record of the pressures, as employed to great advantage by M. Esnault Pelterie, builder of the R. E. P. monoplane, some years ago in France.

(4) By means of a whirling table or large rotating arm at the other end of which are carried the forms or planes to be tested. The first aerodynamic testing apparatus, the old 8-foot whirling arm of Rouse, used in 1758, was of this type. Later Lilienthal, Montgomery, Langley, Renard, and Maxim used it to determine pressures on planes, the action of the air in front of a plane, and to test propellers.

(5) By a wind tunnel, of which there are three principal kinds. In the first, used by Eiffel, Prandtl, and Maxim, a huge fan blows air into a restricted passageway, and the air is then conducted through various screens and chambers until it issues past the test surfaces in a more or less uniform, steady current. At Göttingen, the elaborate character of the air passageway and screens renders the air stream practically perfect in its evenness of flow as it passes the test planes. In the second type of wind tunnel, the air is drawn in past the test surfaces by a powerful fan placed behind them. This is designed to avoid the "churned" air that is exhausted from a fan or propeller. Dr. Stanton in England, and Professor Zahm and Glenn H. Curtiss in this country, use wind tunnels of this type. The third type consists of a fan blowing air through a chamber and screens as before, but at the end of the chamber is a nozzle which contracts the stream and greatly increases its velocity. M. Rateau has used a wind tunnel of this type in his laboratory at Paris.

Pressure Measuring Methods. The actual devices for measuring the pressure vary greatly with the different experimenters, and this, no doubt, plays an important part in the variations observed in their results. Pressure gauges, hydraulic apparatus, aerodynamic balances of great sensitiveness, pendulum devices capable of very exact calibration, graphic records on cylinders by movable pointers, electrical contact devices, and comparison systems with standard flat planes, are some of the many methods employed. To measure the actual velocity of the air stream, anemometers are employed, and are either of the rotary cup type (recording on dials), or of the pressure type, in which the pressure of a surface acts through a spring and operates a large pointer.

Only recently, the great differences between conditions of air pressure and air flow inside a room and out in the open have been recognized. The air in a closed room is perfectly quiet and lacks the characteristics of turbulent motion of the open air—characteristics that very likely have much to do with the pressures on the surface of an aeroplane. Although a simple means of determining air pressures, the wind tunnel only slightly approximates flight conditions, and many of the results obtained by this method of experiment are seriously open to question. Whirling arms if small or if rotated at too high a velocity cause the air about them to assume a rotation, and thus render the results of the experiments inexact. Movement in a straight line in the open air is now recognized as the best means of experiment in aerodynamics, and the one that holds the greatest promise of establishing fully and exactly the laws of flight.

Eiffel Experiments. M. Eiffel has already taken a long step in advance over the usual form of experiments with small test surfaces. In his splendidly equipped laboratory at the Champ de Mars, Paris, he has made determinations on reduced reproductions of actual aeroplane types—models equipped with propellers, motors, and running gear built to an exact scale. Despite their small scale, these experiments have proved to be among the most valuable so far and have enabled M. Eiffel to lay down many more fundamental laws that have a direct and important bearing on aeroplane design. One of the most interesting facts he has brought out is that when two identical planes are superimposed, as on a biplane, the lift per unit of surface is less than if the same surface be used as a monoplane. These significant results show that as the distance between the planes is increased from two-thirds to three-thirds and to four-thirds of the depth, the corresponding reduction of unit pressure due to placing the two planes one over the other is 65 per cent, 70 per cent, and 75 per cent, respectively. He has also made extensive measurements on model wings of eighteen different aeroplane types, making especially complete measurements on models of the R. E. P. and Nieuport monoplanes. His investigations on the distribution of pressure over a plane show definitely that the pressure at the front edge is very much higher than most aeroplane constructors suppose, and that at the rear it is very low, often having a negative value, *i.e.*, the air is pressing on the upper surface instead of the lower.

American Experimental Research. Unfortunately, there are few, if any, well-equipped laboratories in this country, such as are to be found in Germany, France, and Russia, and which have proved of such enormous value to the various industries of those countries, as well as to the aeroplane designer. Aerodynamic research is accordingly confined largely to the efforts of private investigators and to the aeroplane building companies, very little having been done by the Smithsonian Institution since Langley's death. Consequently, the results are seldom published, the companies naturally employing the data in connection with their own machines.

Curtiss Laboratory. Curtiss has established an aerodynamical laboratory at his factory in Hammondsport, New York, and this will doubtless be added to until it becomes one of the most valuable in the country. A wind tunnel has been built and was used experimentally for the first time in the fall of 1911 for studies of the stream lines about the wings and body of the new Curtiss hydroaeroplane, a small model being employed for the purpose. This tunnel is of the suction type, a 30-inch electric suction fan drawing air through a screen at the opposite end, while windows inserted in the tube permit of observation of the action of the model, smoke being introduced into the tunnel to make the action of the stream lines of the model more apparent. The air enters the screen at a part of the room free from obstructions and well above the floor, a fine silk thread suspended in the current showing a deviation of but a small fraction of a degree from exact parallelism with the walls of the tunnel. Two methods have been employed by Curtiss to delineate the stream lines of the air current flowing past the model inside the tube. One is the introduction of smoke already mentioned, and the other is to attach a silk thread to a fine wire and hold it at different points about the model. Both models show the flow at all parts of the current except where the eddies are so violent as to make the thread flutter and the smoke streams break and lose their identity. The thread is more convenient to use than the smoke, but if too long will not accurately coincide with the stream line, owing to the effect of tension. The smoke coincides with the direction of flow at all points and, as Professor Marey has demonstrated, may even indicate the velocity at all parts of the current, if the smoke streams be emitted from nozzles vibrating at a known rate transversely to the current. In this case, the smoke streams are wavy and show by the number of waves per inch the speed of the current at the point of observation. The number of waves per inch may be readily counted on a photograph of the model showing the smoke streams surrounding it. Indeed, the velocity and direction of flow for an entire longitudinal section of the current about the model may be realized at a glance from a photograph of this kind.

Various methods of producing satisfactory smoke lines have been experimented with by Curtiss. At first, air was drawn over the surface of ammonia in a bottle, thence over hydrochloric acid in a second bottle, and then through holes in a tube placed across the current, but the vapor thus produced is pale and requires good lighting in the dark wind tunnel to render it distinct enough for easy observation and photographing. The absolute velocity of the air in the Curtiss wind tunnel was found to be 25 miles per hour at the center of the current, the relative velocity at different parts of a section of the current being ascertained by observing the deflection produced upon a straight exploring wire 10 inches long suspended from a horizontal wire fixed transversely to the stream. When the point of suspension of the exploring wire was moved across the tunnel, the suspended wire was deflected less and less as it advanced from the mid-section toward the lateral wall. The impact pressure of the air against the wire is proportional to its displacement along any longitudinal line of the current. Hence, the velocity is as the square root of such displacement. In this manner, the speed of the current was observed to decline about 2 per cent from mid-stream to within 2 inches of the lateral wall, the tunnel being rectangular in form, and not cylindrical as are those employed in the Continental laboratories.

Curtiss also carried out some very practical tests in connection with the types of hydroaeroplane produced in 1911, as well as the regular models. These included tests of the stresses in the stay wires of all the panels of the main sustaining surfaces of the standard Curtiss biplane, in order to compare them with those determined by computation and graphical construction. For this purpose, the aeroplane was turned upside down and supported at its center. The entire main planes were then loaded with sand, distributed in such a manner as to produce in the guy wires the same stresses as are caused by flight. When subjected to full stress, each wire was tested by means of a pair of tension tongs. The jaws of these tongs have slots to pass over the wire to be tested and they grip it firmly when the slots are closed by tightening screws. When the jaws were thus attached to a wire under stress, the handles of the tongs were drawn together just sufficient to cause the small piece of wire between the two points of attachment to slacken, showing that it was no longer under stress. The force acting on the long handles was then measured by a spring balance, the tension in the wire being found directly as the product of the force indicated by the spring balance multiplied by the leverage, *i. e.*, the ratio of the distances from the pivot of the tongs to the spring balance and to the wire under test.

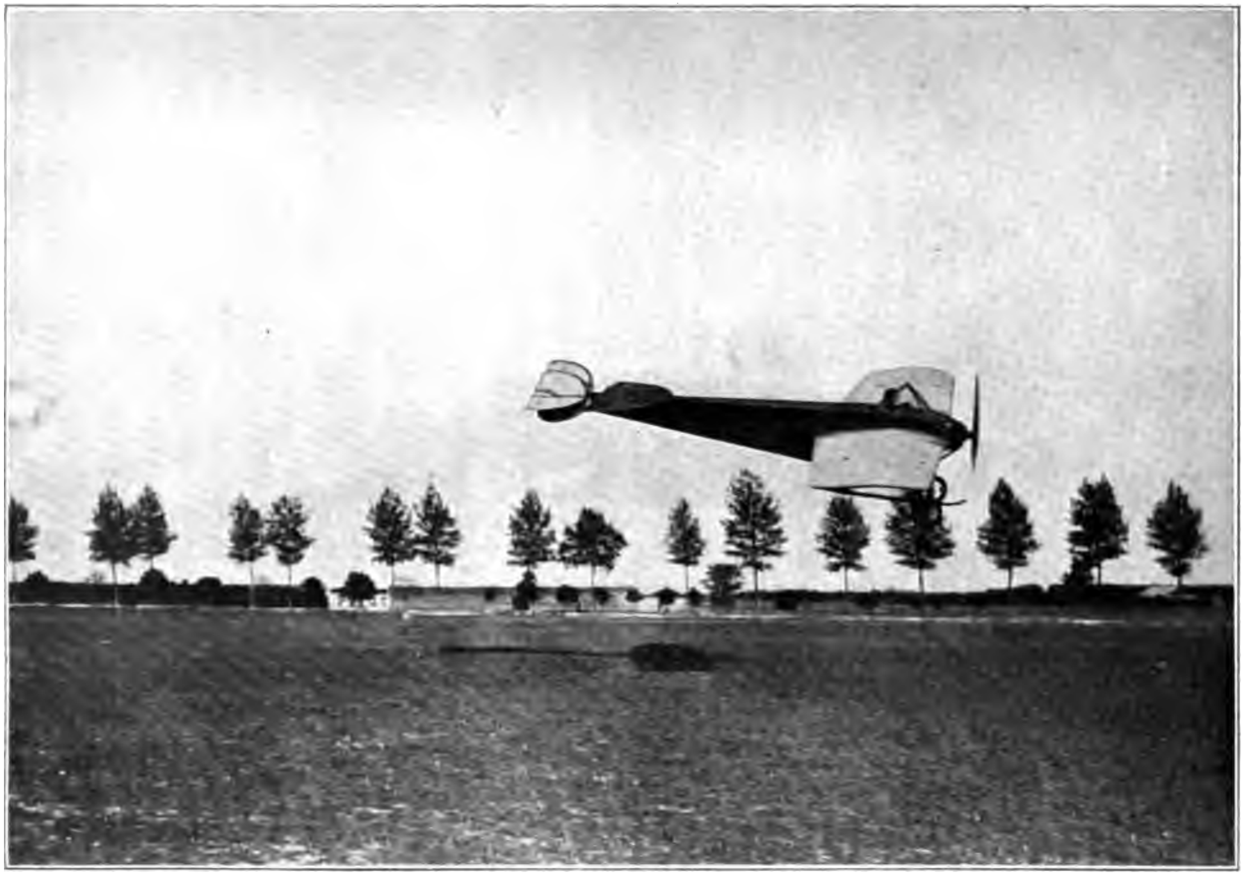
It had been shown previously by analysis and graphic statistics, that in a biplane whose surfaces have practically a uniform running load from center to either wing tip, as may be roughly assumed to be true in ordinary practice, the stress in the outward and upward-sloping stays of the end panels, or wing tips, represents but one-fourth as much tension as the corresponding wires in the second panels from the end, while those wires which slope outward and downward sustain no material tension due to pressure on the concave side of the wings, though they may be very severely strained when the machine is jolting over rough ground. In the third section from either wing tip, known as the engine section, the tension in the guy wires and oblique stay rods is still greater, being more than five times the tension in the wires of the end panels.

Though the tests were made for practical rather than scientific purposes, the stresses were found to increase from the wing ends to the engine section approximately as indicated by theory. It was observed also that each wire had a large factor of safety, ranging from about 10 to 30. Curtiss then added his weight of 150 pounds to one wing tip, while an assistant of equal weight stood on the other wing end. The stress in the wires of the second panel was then doubled.

Other tests were made on the ribs of the main planes, and it was noticed that they were sprung by the load of sand sufficiently to change the tension perceptibly in the fore-and-aft diagonal wires. A panel of the main planes was placed upside down with its spars resting on the trestles placed transversely to the ribs. When uniformly loaded with sand weighing ten times the usual pressure on the wings, the latter collapsed, due to breakage of the ribs. From these various tests, it was concluded that the weakest part of the machine had a factor of safety of ten, *i. e.*, it would not give way until subjected to ten times the stresses usually encountered in ordinary flight.

In addition to the tongs referred to, two other contrivances were devised for testing the tension of aeroplane wires, one being an instrument for giving the pitch of the wire under vibration, while the other was an instrument for showing the lateral displacement of the wire by a given force, from which the tension could be read in a reference table or along a specially-designed index scale, all of the instruments in question being developed by Curtiss experimenting in collaboration with Dr. Zahm.

With all that is being done in these and numerous other laboratories, the subject has been scarcely more than touched upon, though the investigations already carried out have laid the foundation for the scientific construction of the aeroplane. With the cumulative data gained by numerous experimenters, it will doubtless be possible in the course of comparatively few years to solve problems the solution of which at present seems very far in the future, and that otherwise might never be definitely settled.



TWENTY HORSE-POWER NIEUPORT MONOPLANE MAKING A LANDING

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TYPES OF AEROPLANES

PART I

STANDARD TYPES

General Survey. In view of the fact that aeroplane design can hardly be said to have progressed beyond its inception, it may appear to be somewhat of a misnomer to refer to standard types. There are, however, a certain number of designs in biplanes and monoplanes, constructed according to well-defined models, and after which the majority of others are patterned. While these are more or less similar in their fundamental characteristics, they vary from one another in important details of size, arrangement, and efficiency of their parts. For the purpose of comparison, a discussion of their distinguishing features, as well as their merits and demerits, is appended. A study of this will be found of the greatest value as a means of obtaining a knowledge of the chief characteristics of the best-known aeroplanes.

The fifteen most prominent and distinctive types are described in detail, the order in which they are taken up not being based on any quality of the machines themselves. The biplanes are eight in number, as follows: Wright, Wright Racer (Baby), Curtiss, Voisin, New Model Voisin, Farman, Sommer, and Cody.

The monoplanes are seven in number, as follows: Antoinette, Santos-Dumont, Bleriot XI, Bleriot XII, Grade, Pelterie, and Pfitzner.

With few exceptions the machines in question as described in the following paragraphs have been flown thousands of miles and used over extended periods by a great number of aviators and amateurs, and they have likewise been copied in hundreds of other machines, but as the result of the experience thus gained, their builders have inaugurated various changes, not merely of dimensions, but of construction in some cases and of principle in others. Most of these changes have been brought about during 1911. In not a few instances, the changes have been of sufficient importance to warrant giving the new machine a new title. Wherever the changes have altered the machine materially, the details are given just after the description of the standard type.

In addition to the foregoing, there are some special types the distinguishing features of which merit reference. Many other types of successful biplanes and monoplanes are in use, but they differ so slightly from one or another of those described here that any detailed mention of them would only lead to confusion. The great number of machines now being built in this country by individual experimenters or by manufacturers are either replicas of those detailed or are modifications of them.

Nomenclature. Despite the phenomenally rapid development of aviation, its terminology has kept pace so that there are a number of expressions the meaning of which must be explained before attempting a description of the machines themselves.

SUPPORTING PLANE. By supporting plane is meant the main lifting surface as distinguished from all auxiliary or stabilizing surfaces.

DIRECTION AND ELEVATION RUDDERS. Direction rudder refers to the movable, vertical surface used for steering to the right or left, while the elevation rudder is a horizontal surface the function of which will be obvious.

TRANSVERSE CONTROL. Transverse control is the device employed for the preservation of lateral balance when flying straightaway and for maintaining an artificial inclination of the machine when rounding turns.

KEELS. Keels are fixed surfaces intended to aid in the preservation of stability; they exert neither lifting effect nor rudder action.

SPREAD. Spread is the maximum horizontal dimension perpendicular to the line of flight.

DEPTH. Depth is the dimension of the plane parallel to the line of flight.

ASPECT RATIO. By "aspect ratio" is meant the proportion of spread to depth and it constitutes a factor for defining the shape of the supporting plane.

For the purpose of more clearly showing the variation in size of the different types, detailed and dimensioned plans and elevations of each machine are given. Most of these are drawn to the same scale, thus enabling a direct, graphic comparison of the types. But it must be borne in mind, inasmuch as aviators are constantly changing and rechanging the dimensions of their machines, without recording such alterations, many of the dimensions given here are necessarily approximate. In all cases, however, the most recent and accurate data, as furnished by the large number of references consulted as well as by close personal inspection, has been employed.

BIPLANES

Wright. This Wright machine, Fig. 1, is the original Wright type of which many are made and used in England, France, and Germany, there being Wright companies in those countries devoted to their manufacture and exploitation. The more recent Wright machines do not require a rail or weight for starting and the front elevation rudder has been discarded. Among the biplanes the Wright is almost twice as efficient as any other type, this being ascribed by French writers, particularly Berget, to the fact that a great deal of weight is saved by the starting device. This is what the latter was originally adopted for, but as no increase in power was found necessary when it was discarded for the four-wheeled chassis now employed, the contention does not hold good. In view of its much rougher construction as compared with the finely finished French machines, its efficiency is extremely high, owing in large measure, doubtless, to the employment of two propellers revolving at a comparatively slow speed.

Frame. Clear spruce and ash are used throughout in the construction of the frame, which is very simply but solidly built. The bracing wires are steel and are made to fit exactly, while the struts or separators are of elliptical form with the small edge facing the direction of motion. These struts are equipped with hooks at each end fitting in rings in the frames of the two planes. All exposed parts of the machine are painted with an aluminum mixture.

Supporting Planes. Two identical and superposed surfaces of canvas (fine, closely woven duck) stretched over and under wood ribs of light but strong built-up construction support the machine in the air. These surfaces, or planes, are 3 inches thick near the center and have a somewhat flatter and more regular curve than that commonly employed. The planes, which are spaced 6 feet apart, have a spread of 41 feet, a depth of 6.56 feet, and a total area of 538 square feet.

Elevation Rudder. In the Wright biplane the rudder is so constructed that when elevated it is automatically warped concavely on the under side, and when depressed it is curved in the opposite way. This materially adds to the force exerted. It is double surfaced, constituting a small biplane itself and has 70 square

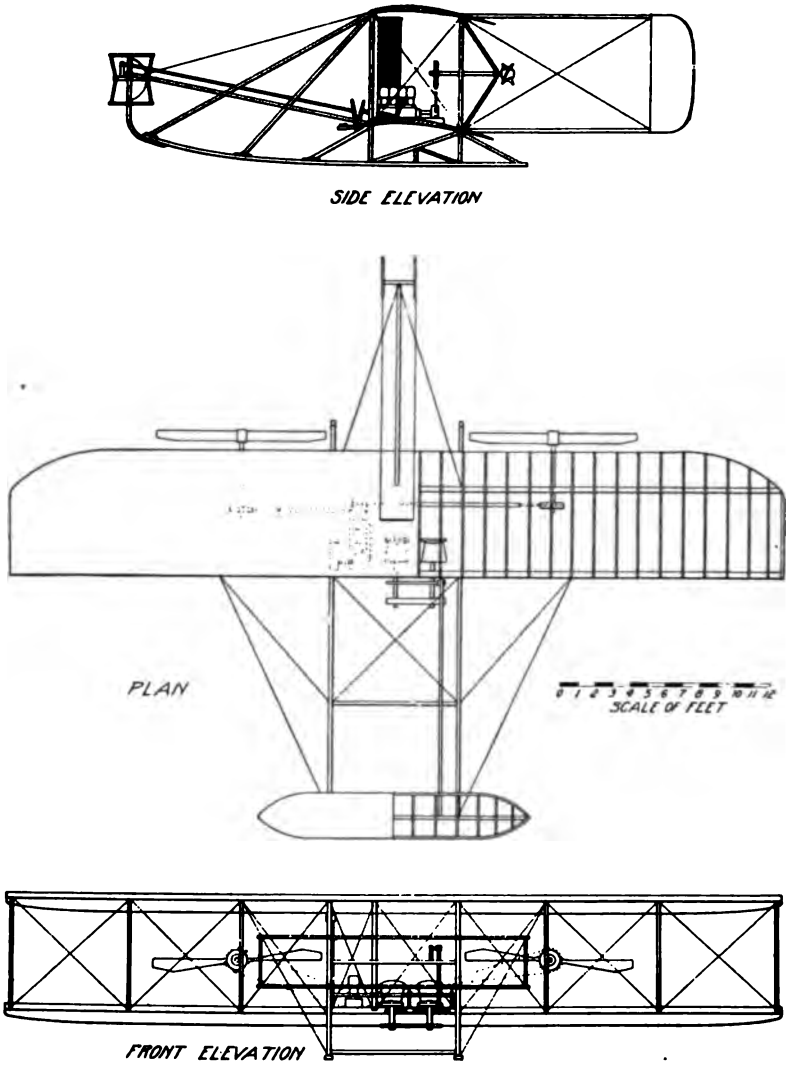


Fig. 1. Original Type of Wright Biplane

feet of area; it is placed well forward of the main planes, being supported on an extension of the landing skids. This rudder is controlled by a lever worked by the operator's left hand. To rise, the aviator pulls the lever toward him. This motion, transmitted to the rudder mechanism by a long, wood connecting rod, causes the rudder to turn upward relative to the line of flight and consequently the machine rises. Reversing the movement causes it to descend.

Direction Rudder. The direction rudder is placed in the rear on the center line, and consists of two identical and parallel vertical surfaces with a total area of 23 square feet. It is governed by the right-hand lever, turning to the left being accomplished by pushing out and to the right by pulling in on it. The control is not employed exactly in this manner, however, as a sidewise movement of the same lever also serves to warp the planes—a feature indispensable to lateral equilibrium in rounding turns. The two motions of the lever are very intimately connected in their effect upon the control.

Transverse Control. Transverse control is the famous warping device invented by the Wrights for the preservation of lateral balance and for artificial inclination in making turns, and is employed in a similar or modified form in almost every aeroplane thus far constructed, the Pfitzner monoplane constituting the most radical departure from it. To permit of this warping, the rear vertical panel of the main cell, or double plane, is divided into three sections. The central panel is solidly braced and extends on either side of the center to the second strut from each end. From these struts, the rear horizontal crosspieces are merely hinged instead of being continued portions of the crosspiece at the center, and the two vertical panels on either end are not cross braced. These two rear end sections of the cell are, therefore, movable vertically. The entire front of the machine, as well as the ribs inside the supporting planes, however, are perfectly rigid, there being no helical torsion of the ribs themselves, as commonly supposed. Cables connect these two sections of the planes together and lead to the right-hand lever. The operation is as follows: If the machine suddenly tilts or dips down, at the right end, for example, the lever is moved to the left. This action pulls down the rear right ends of the surfaces and at the same time pulls the left ends upward. An increase in the incident angle of the outer end of the plane on the depressed side and a decrease of the incident angle on the opposite side, are thus brought about, righting the machine at once. During this operation, the entire front face of the cell as well as the rear central section remain perfectly rigid in every sense.

The warping apparatus is also interconnected with the direction rudder and the simultaneous action of both is depended upon. This is one of the chief claims of the original Wright patent, and in actual practice the direction rudder and transverse control of the machine are rarely, if ever, worked separately. To make a turn to the left, for example, it is evident that if this same lever is moved in an arc, outward and to the left, somewhat similar to the contour of the desired turn, not only will the surfaces be warped so as to raise the right end, but the direction rudder is also set to give the desired change of travel, and the combined action of the two is prompt and very effective.

Fig. 2. Tail of Short Wright Biplane Showing Addition of Horizontal Keel at Rear

There are no keels on the original Wright biplane, but since the elimination of the forward elevating rudder, these have been introduced in the later type, Fig. 2. In the older machine, a small, pivoted, vertical surface is placed in front to indicate any change in direction of the relative air current.

Power Plant. The power plant consists of a four-cylinder, vertical, four-cycle, water-cooled motor built by the Wrights themselves and rated at 25 to 28 horse-power, which drives two double-bladed propellers in opposite directions by chains and sprockets. The propellers are of laminated wood construction, made of clear spruce, measuring 8.5 feet in diameter and having a 9-foot pitch. They rotate at 400 r.p.m., or only about one third the speed at which the usual single propeller is ordinarily driven, and are placed at the rear of the main cell, at equal distances on either side of the center.

Running Gear. As already mentioned, the original mounting was on skids only, but since about July, 1910, all of the Wright machines have been fitted with four pneumatic-tired wheels attached to a rectangular frame. The total weight of the machine described above is 1,050 to 1,150 pounds and the speed 40 miles per hour; 41 pounds are lifted per horse-power of the motor and 2.05 pounds per square foot of supporting surface. The aspect ratio is 6.25 to 1. These figures, however, apply only to this particular machine, as the Wright biplane built for the United States Signal Corps, as well as those constructed by the Aerial Company of France, have a spread of only 36 feet with a total supporting surface of 490 square feet.

Fig. 3. Brookins in Headless Wright Just About to Leave the Ground

French Wright. In the French Wright machines, the aviator sits next to the motor, and when instructing Count Lambert and

M. Tissandier in the winter of 1909 at Pau, Wilbur Wright had fitted to the machine an extra lever to control the elevation rudder on the right side of the passenger who sat next to the motor. The position of the levers for the passenger was, therefore, the reverse of the usual one. Messrs. Tissandier and Lambert, having learned to operate in this manner, have never changed, but as they in turn have become the instructors of many purchasers of Wright machines, their pupils are taught to control in the normal manner.

New Model Wright. The new Wright machine, introduced in the summer of 1910 and first seen in public at the Asbury Park Meet, has no front elevation rudder and was, therefore, popularly dubbed the "headless" Wright, shown in Figs. 3 and 4. The elevation of the machine is controlled by the rear horizontal surface alone. This machine is also smaller and faster, its spread being 39 feet, depth 5.5 feet, and supporting surface 410 square feet. With the 30-horse-power motor employed, the lift is 37 pounds per horse-power, or 2.5 pounds per square foot of surface. The aspect ratio is 7.1 to 1.

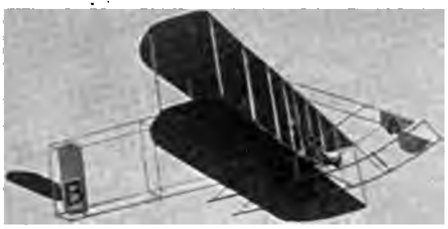


Fig. 4. Headless Wright in Flight

Wright Racer. The Wright Racer is officially known as "Model R" by the manufacturers, but owing to its diminutive size was immediately christened the "Baby Wright" on its first appearance at the International Meet at Belmont Park in 1910. It was especially designed for high speed and one of this model with an eight-cylinder motor was entered in the Gordon-Bennett cup race, but owing to an accident it did not take part. This machine is shown in Fig. 5 with Orville Wright driving, Hoxsey holding the machine on the right, and Brookins on the left. As the engine is running, the propellers do not show in the illustration. Sufficient accommodation only for the aviator is provided so that it is a one-man machine. It is said to be the fastest climbing aeroplane ever built, Johnstone's record of 9,714 feet made at Belmont Park having been accomplished on this model.

Frame. This machine is of the same headless type as that brought out in the larger size during the early part of 1910. The construction of the frame throughout is the same as in the latter.

Supporting Planes. The supporting planes are of the same design and construction as in the larger machine, but they have a spread of only 26½ feet by a depth of 3 feet 7 inches, giving a total area of but slightly over 185 square feet. The length fore and aft is 24 feet, while the height from the ground to the top of the upper plane is but 6 feet 10 inches.

Elevation Rudder. The elevation rudder, as well as the direction rudder, is of the same design, construction, and operation as the standard Wright flyer, the dimensions merely being made to correspond to its smaller size.

Fig. 5. Wright Baby Racer, with Orville Wright at the Wheel

Transverse Control. The regular Wright warping device in connection with the control of the direction rudder is employed, as in the larger machines.

Power Plant. The power plant is an eight-cylinder, V-type, 50- to 60-horse-power motor which is characterized by the same features of design as the standard Wright four-cylinder motor used on the larger machines. It drives two two-bladed wood propellers in opposite directions through the medium of chains and sprockets, and, so far as may be noted by a casual examination, they are identically the same as those employed on the regular Wright machines and are designed to run at the same speed, *i. e.*, about 400 r.p.m., the speed of the motor being 1,300 r.p.m.

General. The seat for the aviator is directly in front of and in line with the motor and there is no provision for carrying a passenger, owing to the extremely small size of the machine. It is, in fact, a "fly-about," to coin a term analogous to that prevalent in the automobile field. The machine is mounted on two pairs of pneumatic-tired wheels straddling each of the skids and placed directly under the center of the machine.

The weight of the machine alone is only 585 pounds, its total weight in flight ranging from 735 to 800 pounds, thus lifting 13.3 pounds per horse-power, taking as a basis the maximum weight of 800 pounds and putting the horse-power of the motor down as 60. On the same basis of total weight, the loading is 4.27 pounds per square foot of surface. The aspect ratio is 7.4 to 1.

Wright Model B. In automobile parlance, this is the standard 1912 Wright Model, and while it shows few or no departures from the principles already established in its predecessors, it is distinguished by a number of refinements. The spread is 39 feet and the chord 6 feet 2 inches, the main planes being built in three sections and covered with Goodyear rubberized fabric in place of the canvas formerly employed. The fabric is laid diagonally and is attached to each section independently, the sections being laced together when the machine is assembled. The main spars are of spruce, as is most of the rest of the woodwork, 1¾ × 1¼ inches, the greatest dimension being vertical in the front spar and horizontal in the rear spar. They are larger in the middle section of the lower plane, ash being used in the rear of the latter. There are 34 ribs to each plane, spaced a foot apart in the center and wider toward the lateral extremities of the planes. The ribs which come near struts are solid between the main spars, the others being built up of an upper and lower strip with blocks spaced about six inches as distance pieces. The two ribs that support the engine and the two seat ribs are the only ones between the spars of the lower main plane in its center section. There are nine pairs of uprights of various sizes, the outer two sets on each end being secured to the planes by the familiar flexible joint, the remainder having a form of socket joint. A few turnbuckles have made their appearance in the center section, doubtless to facilitate replacement of the engine or other parts. All the steel piano wires not fitted with turnbuckles are cut to length and are interchangeable. When setting up the planes, the wires are attached and the struts then sprung into place. These guy wires are cut and the loop bent by a special machine at the factory. As the wire employed has a breaking strength of 800 to 2,400 pounds, according to size, there should be no occasion for adjustment on account of stretch. The curve of the planes is 1 in 20, the greatest depth being two fifths of the chord back from the front edge. The aspect ratio is 6.25 to 1.

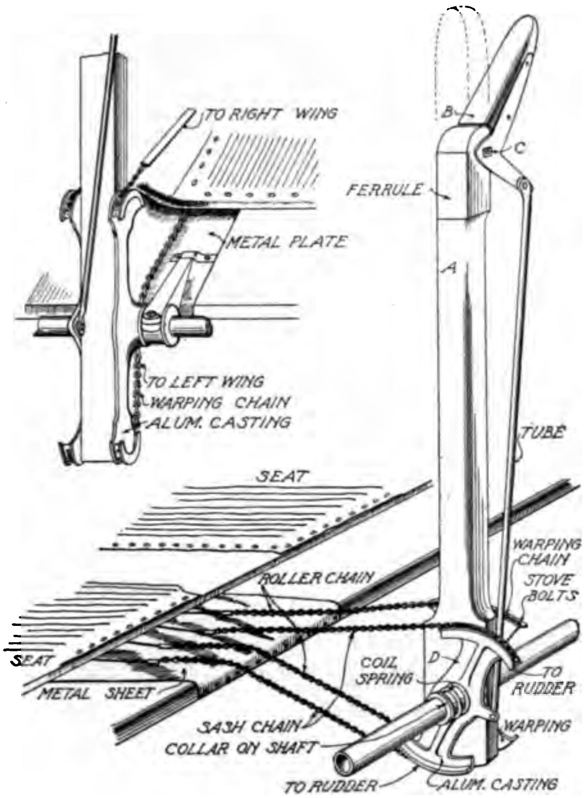


Fig. 6. Details of Wright Model B Combination Warping and Direction Lever

The small semicircular fins or "blinkers" familiar on the 1910 machine have given place to two sets on the latest machines, due to the fact that greater area is required as the skids have been shortened, thus bringing these surfaces closer to the main planes. Their shape is that of small jibs.

The vertical rudder is, in general, of the same construction as in the earlier models, though somewhat smaller. The rudder is operated by the combination warping and direction lever, Fig. 6. As shown, this lever also warps the wings. By "breaking" the top section *B*, either to the left or to the right (without moving the rest of the lever from its position), the rudder is moved only to steer left or right, respectively. In making flat turns, without banking, the top section only of the lever is used. The movement is entirely a natural or instinctive one. This separate movement of the rudder is obtained by having the sector *D*, movably mounted, capable of individual action with respect to lever section *A*, through the steel tube actuated by the section *B* of the lever. The wire which goes over the top of sector *D* must go to the left side of the rudder cross bar.

The front third of the elevator surface is held rigid while the remainder is flexible. This is operated by a forward and backward movement of the elevator lever, the wires being crossed so that pushing out on the lever steers down and pulling toward the operator causes the machine to ascend. The cloth is laid on diagonally and only one surface is used, the ribs and spars running through pockets in the cloth. There is a second elevator lever which can be used by a student passenger, who would then work the warping lever (and rudder) with his right hand. Some of the Wright aviators use the seat next to the engine with the warping lever at the left, while others sit on the outside seat. This second elevator lever has a disk attached, encompassed on its periphery by a flat steel friction band to hold the lever in any set position.

While the control of the machine does not appear to be instinctive, it certainly is very easy to learn and, after having it once impressed upon the mind, is very satisfactory. It would seem that the exertion of moving the warping lever fore and aft is a great deal less than if it were arranged to move sideways as in some other machines. The warping is effected by the lever *A*, Fig. 6. Pushing forward raises the left wing and depresses the right; the same movement turns the rudder to the left—besides having a lesser angle of incidence, when the lever as a whole is used. The wiring for the warping is shown in the diagrammatic sketch, Fig. 7. The rear spars of the two end sections of the planes are hinged to those of the center section, so that warping may be accomplished without flexing the spar. The lever arrangements have varied on many of the machines. Some are flown with the aviator using the left hand for warping. Students taught by these use the right hand for warping, as a rule, and this is now the practice in "breaking in" flyers in order that any passenger or other weight they may carry will occupy a central position on the machine and retain the balance. However, one or two machines have been put out with two warping and two elevating levers, for those who desire to fly together, both having learned the use of the same hand for warping.

Referring to the combination warping and rudder lever, Fig. 6, the lever *A* is jointed or hinged at the top. The short section *B* turns left or right on the axis *C* for independent rudder action. The lever as a whole moved forward warps the left wing up and the right wing down, at the same time turning the rudder towards the left, to offer resistance to the side having the lesser angle of incidence. The elevator is also warped down to enable the machine to gain speed, and the aeroplane has begun to bank, the right side being the higher. Next, this combination lever as a whole is gradually brought back to normal position, as the aeroplane is now at almost a forty-five degree angle. At this stage with this lever (as one) normal, and the wings straightened out, the top section of the lever is "broken" over to the left, which turns the rudder only to this side. This operation is gone through in making short circles, or spirals, for which the Wright machine is famous. For right

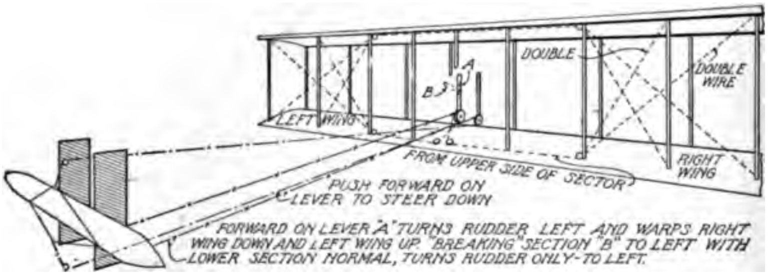


Fig. 7. Diagrammatical Sketch of Wright Control-Mechanism

spirals, the reverse of the operation just described must be carried out, care being taken to straighten out before the machine has banked at so steep an angle as to make recovery impossible. In Fig. 6 the section *B* is broken to the left, turning the rudder only in that direction.

The motor on this machine does not differ except in a few details from that which the Wright Brothers have been building for their own machines ever since they began flying. One of the innovations consists of an emergency shut-off of the power, consisting of a wire conveniently placed over the aviator's head. Pulling this raises the exhaust valves and thus cuts off the power of the motor, without bringing it to a sudden and dead stop, as in the case where the switch for short-circuiting the Mea magneto is closed. The power can thus be cut down considerably without bringing the motor to a stop. The same method of feeding the gasoline directly to the inlet manifold by means of a gear pump, and without a carbureter, is still retained. As its speed increases with that of the engine, the amount of fuel fed is always in proportion to the latter's speed. Retarding or advancing the spark is accordingly the only method of controlling the speed of the motor, apart from the exhaust valve control previously mentioned. A pedal in front of the aviator sets the spark back to facilitate safe starting of the motor, and the magneto is provided with a catch to hold it in the retarded position, so that an aviator may start his own machine without danger of having it run away from him before he can get into the seat. The weight of the bare engine is 180 pounds and it consumes about 4 gallons of gasoline per hour, the 12-gallon tank accordingly providing sufficient for a three-hour flight.

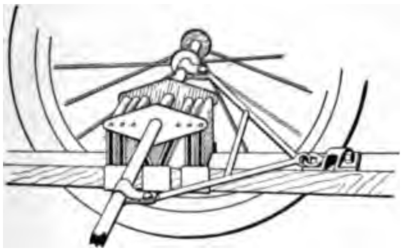


Fig. 8. Wheel Mounting Details, Wright Model B

The engine is mounted at either end of the base on cross members, which in turn rest on the solid engine foundation ribs. Duplicate sprockets, which are screwed and locked to the crank shaft back of the flywheel, drive by means of special roller chains the

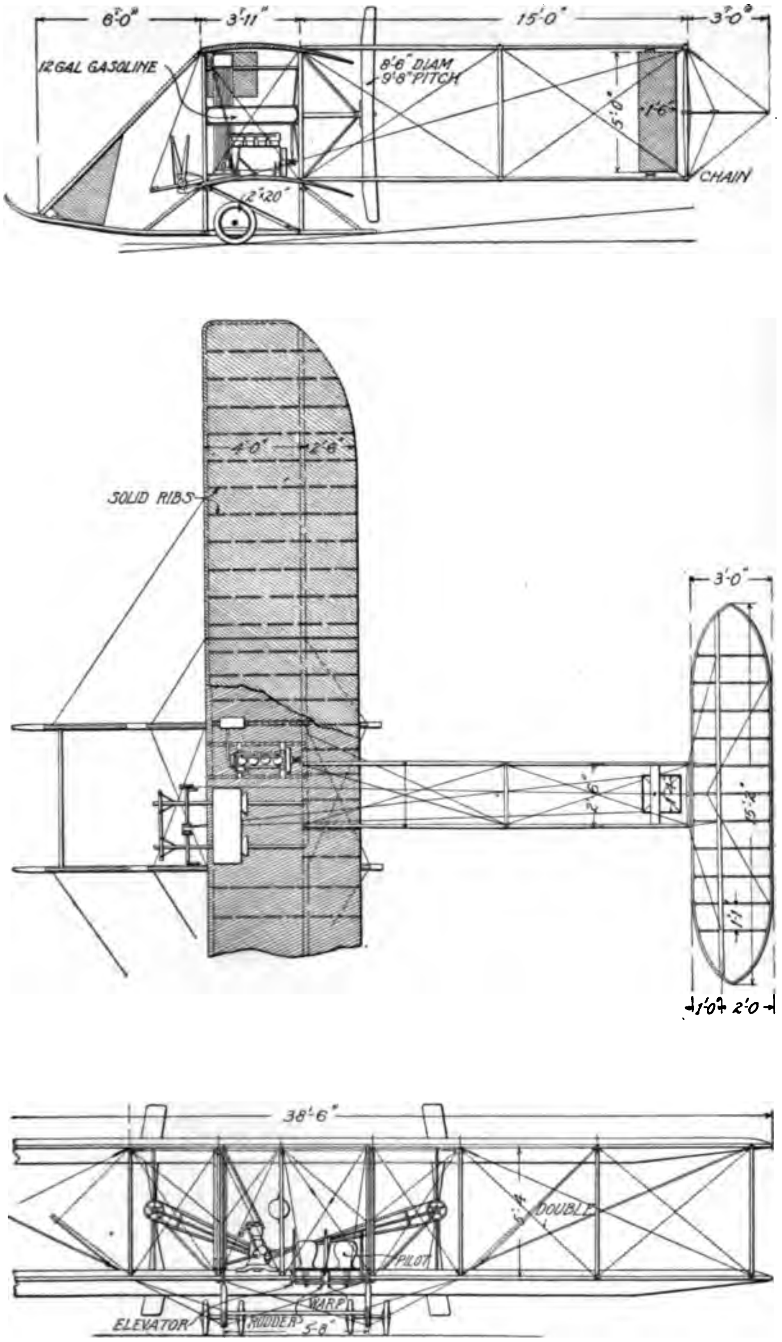


Fig. 9. Detailed Diagrams of Wright Model B

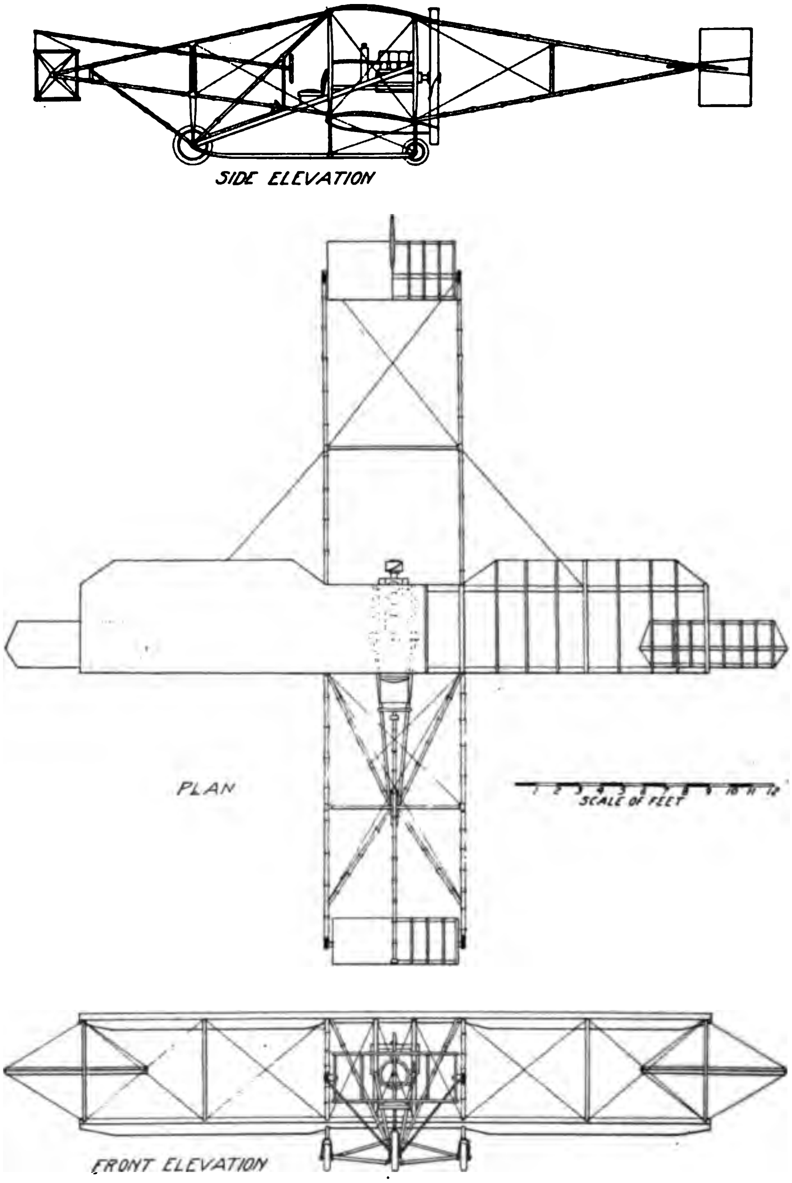


Fig. 10. Detailed Diagram of Curtiss Biplane

two propellers, their speed being geared down in the ratio of 11 to 34. At an engine speed of 1,325 r.p.m., the propellers turn at

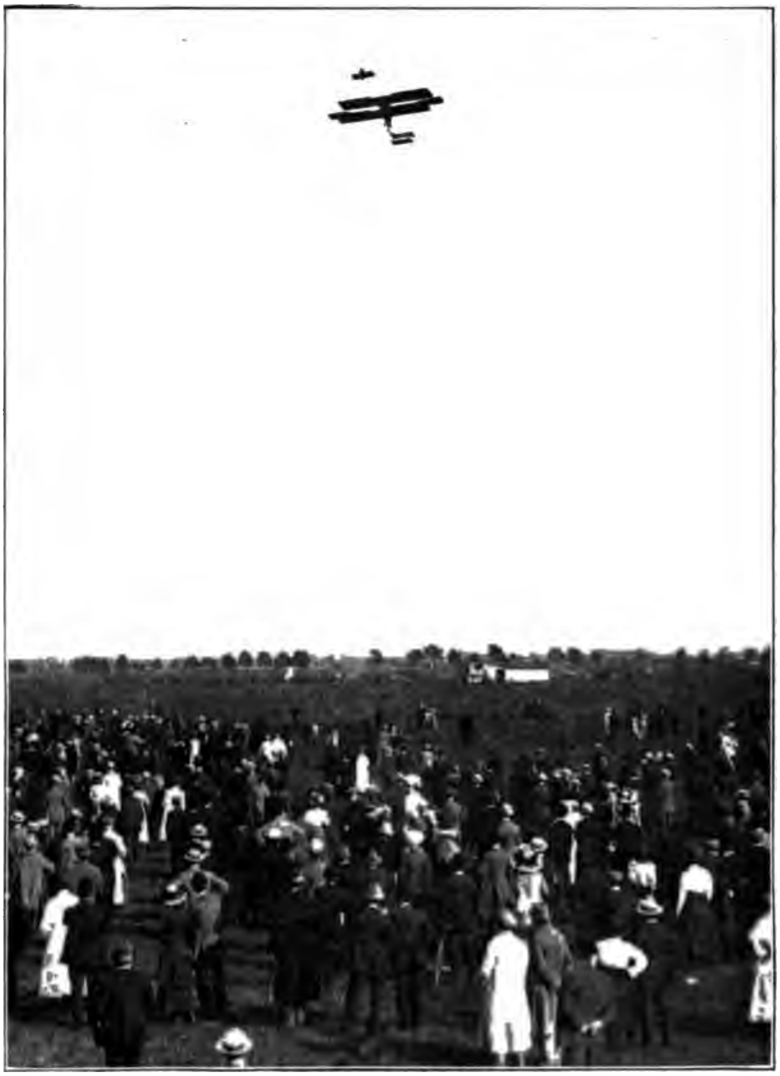


Fig. 11. Curtiss on His Trip from Albany to New York City. Leaving Poughkeepsie

428 r.p.m., giving a flying thrust of about 250 pounds. Adjustable stays are provided for tightening the chains.

For the landing gear, wheels are used in combination with the usual skid arrangement, the skids themselves having been very much shortened. The method of mounting the wheels is illustrated in Fig. 8. The complete machine is illustrated in Fig. 9.

With operator and passenger, ready to fly, the machine weighs about 1,250 pounds. The weight thus carried per horse-power is about 40 pounds, while the loading on the above basis figures out at but 2½ pounds per square foot. Lancaster gives the Wright machine an efficiency of 63 per cent, after deducting 5 per cent for loss in the chains. In a book by Eiffel (1911), it is stated that 30 horse-power is required to fly the Wright machine, which, in view of the facts, is obviously an erroneous conclusion.

Fig. 12. Curtiss on His Albany to New York Trip. Flying Down the Hudson

Curtiss. The Curtiss biplane, Fig. 10, embodies in its construction several features that distinguished the aeroplanes built by the Aerial Experiment Association, of which Glenn H. Curtiss was a member. The first flight of this type was made in June, 1909. At Rheims, France, in August of the same year, this miniature biplane captured the Gordon-Bennett trophy as well as several other prizes, under the able guidance of Curtiss. A number of these machines are being flown and have a great many estimable performances to their credit, such as the flight of Curtiss from Albany to New York, illustrated in Figs. 11, 12, and 13, and Ely's flight from the deck of a man-of-war to the shore and back. The Curtiss is one of the fastest biplanes in use.

Fig. 13. Curtiss Rounding the Statue of Liberty

Frame. The main cell and smaller parts are made of ash and spruce, while the long outriggers are of bamboo, several of the members of the frame meeting at the front wheel of the landing chassis. Small steel cables and wires are employed for bracing.

Supporting Planes. The supporting planes consist of two identical directly-superposed surfaces made of one layer each of Baldwin rubber silk tacked to spruce ribs and laced to the frame, and are of highly-finished construction. A distance of 5 feet separates the two surfaces. Their spread is 26.42 feet, depth 4.5 feet, and total area 220 square feet.

Elevation Rudder. The elevation rudder is a small biplane cell having two similar surfaces of a total area of 24 square feet and mounted on bamboo outriggers on the meeting point of which it is pivoted, Fig. 14. It is controlled by a long, bamboo pole attached to the stanchion on which the steering wheel is mounted. To descend, the operator pushes out on the wheel, and to ascend draws it toward him. In Fig. 14, Curtiss is shown at the wheel.

Direction Rudder. For steering to right or left, a single, vertical surface of 6.6 square feet of area is pivoted at the meeting point of a similar pair of bamboo outriggers extending to the rear. It is operated from the steering wheel by cables running through the hollow outriggers.

Transverse Control. Transverse control consists of two independent balancing planes, or ailerons, of 12 square feet area each, which are shown very clearly in Fig. 15. They are placed at each end of the main cell and are pivoted midway between the upper and lower main planes. They are designed to preserve the lateral balance and are tipped inversely by means of a brace fitted to the aviator's shoulders and controlled by the movement of his body. If the machine is depressed on the left side, the aviator leans to the right and in doing so shifts the brace, causing the aileron on the left side to turn down and the one on the right to turn up, the two being interconnected by cables, thus righting the machine. By "turning down" in this connection is meant a motion relative to the axis of the aileron itself and not to the line of flight. In other words, it swings on its supporting shaft. When turned down, its incidence, *i. e.*, the angle it makes with the line of flight, is positive

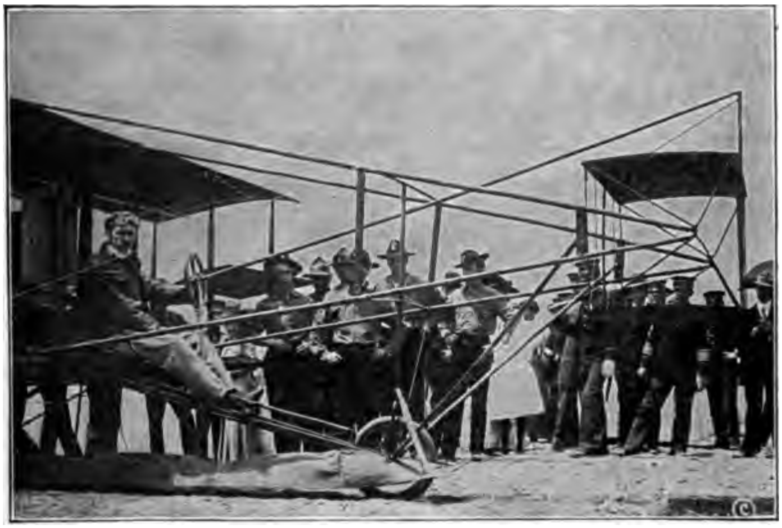


Fig. 14. Elevation Rudder and Steering Gear on Curtiss Machine

and it therefore exerts a greater lifting force. When making a turn to the right, for instance, the aviator by leaning to the right, thus causing the left end to lift, can make a much sharper turn than with the use of the direction rudder alone, while the lateral balance is also preserved.

Keel. A horizontal fixed surface, or keel, is placed in the rear and has an important steadying effect. Its area is 15 square feet. A small, triangular vertical plane is sometimes placed in front and aids in turning.

Power Plant. In the original machine the power plant consisted of a four-cylinder, vertical, four-cycle, air-cooled motor of 25 horsepower, placed well up between the two main planes at the rear. It drives a two-bladed wood propeller direct at 1,200 r. p. m. The propeller has a diameter of 6 feet and a pitch of 5 feet. In more recent Curtiss machines, an eight-cylinder, V-type, four-cycle, air-cooled motor of 50 horse-power is employed.

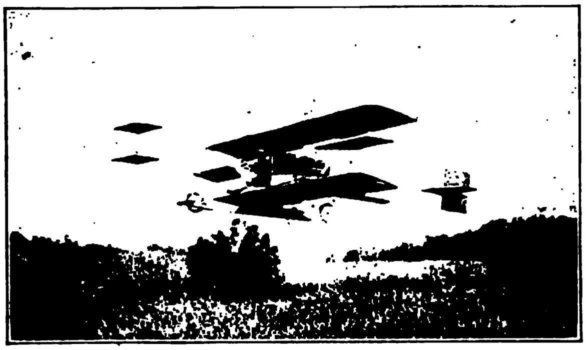


Fig. 15. Curtiss Machine in Flight, Showing Ailerons and Position of Operator

General. The seat for the aviator is on the framing in front of the main cell and in line with the motor, Fig. 15. When a passenger is carried, a seat is provided at one side and somewhat below the aviator. The machine runs on three pneumatic-tired wheels, rigidly fixed to the frame, no springs being provided. The total weight is from 530 to 570 pounds, and the speed is 47 m. p. h.; 22 pounds are lifted per horse-power, and 2.5 pounds per square foot of surface. The aspect ratio is 5.65 to 1.

During 1910, Willard, one of the Curtiss aviators, employed a much larger machine of exactly the same type, in which he succeeded in carrying three passengers besides himself. The supporting planes of this machine have a spread of 32 feet, a depth of 5 feet, and a total area of 316 square feet. The elevation rudder is 31 square feet in area, and the direction rudder 7.5 square feet, while the rear horizontal keel has an area of 17.5 square feet and the ailerons are each of 27 square feet area. A Curtiss eight-cylinder, 50-horse-power motor is employed to directly drive a 7-foot propeller at 1,100 r. p. m. The maximum total weight in flight is 1,150 pounds, thus lifting 22.6 pounds per horse-power, and 3.64 pounds per square foot of surface. The aspect ratio is 6.4 to 1. It was in a machine of this type that Curtiss made his flight from Albany to New York.

At the International Meet at Belmont Park, New York, in October, 1910, Curtiss exhibited a radically different type of machine. (See Fig. 49.) This embodied most of the constructional features already described, but instead of two similar planes there was one very large main surface with an extremely small superposed plane directly above the center of the latter. Though termed a biplane, it was practically a monoplane in everything but name. No opportunity was afforded of seeing what it could do in flight.

In a later type of the Curtiss, the ailerons are pivoted from the rear struts instead of the front ones, this doing away with their interference of the lifting power of the upper main plane. Head resistance has been cut down by double surfacing the planes, thus enclosing the ribs and beams, and also by adopting a single surface in place of the former biplane elevator. The axis of the new elevator is placed only 6 feet 9 inches in front of the main planes and has two short stays of bamboo between the wheel and the elevator instead of the elaborate and complicated structure formerly employed for staying. The rear tail flaps work in conjunction with the elevator, being pivoted at a point about 13 feet to the rear of the main planes. Two triangular stabilizing fins are used instead of the usual plane, their angle of incidence being about 2 degrees, which can readily be changed. The vertical rudder is placed between these two flaps and is pivoted back of its front edge, and it is operated by a tiller post or forward extension, instead of attaching the cables directly to the rudder itself. The span is 30 feet, chord 4 feet 2 inches, and the planes are 4 feet 5 inches apart vertically, the camber apparently not having been changed. The dimensions of the front elevator are 2 feet × 6 feet 3½ inches, with a triangular vertical fin attached to it above. A standard eight-cylinder, V-type, 50-horse-power motor of Curtiss make drives a Curtiss two-bladed propeller, the laminated engine base being supported at the rear by steel tubing, which is also used to brace the entire rear section. In front, the base is bolted to two short laminated struts. The height of the base is 14 inches, and above this a triangle of 1-inch oval steel tubing extends to the top plane, where it is secured by a bolt. The engine is placed 9 inches rearward from the rear beam, and the canvas seat is 8 inches forward of the front beam.

Fig. 16. Delagrange Model of Voisin Biplane

Voisin. The Voisin Brothers began their activity as constructors of aeroplanes as early as 1905, when they built gliders for both M. Archdeacon and M. Bleriot. These gliders were successfully operated over the Seine, being lifted from the surface of the river and towed at high speed by motorboats. In 1906, they built a power-driven machine after the designs of the late M. Delagrange, Fig. 16, and subsequently, after making a few changes in the design, built a machine for Henri Farman, Fig. 17, which was the first successful aeroplane of European manufacture. Since that time, the design of this type has remained substantially the same, except for the addition of several keels, Fig. 18. The Voisin biplane has been largely used abroad, over one hundred machines of this type having been built.

Frame. The frame is made of ash with steel joints and several parts of steel tubing. It consists essentially of a large box-cell

Fig. 17. Henri Farman in an Early Type of Voisin Biplane

mounted on a central chassis, while attached to it some distance in the rear is a smaller box-cell of the same form. This central chassis is really a unit in itself, carrying the wheels, the motor, the aviator's seat, and at the front the elevation rudder.

Supporting Planes. Two main supporting planes of similar dimensions and directly superposed are employed, the surfaces consisting of continental cloth (a cotton and rubber fabric) stretched

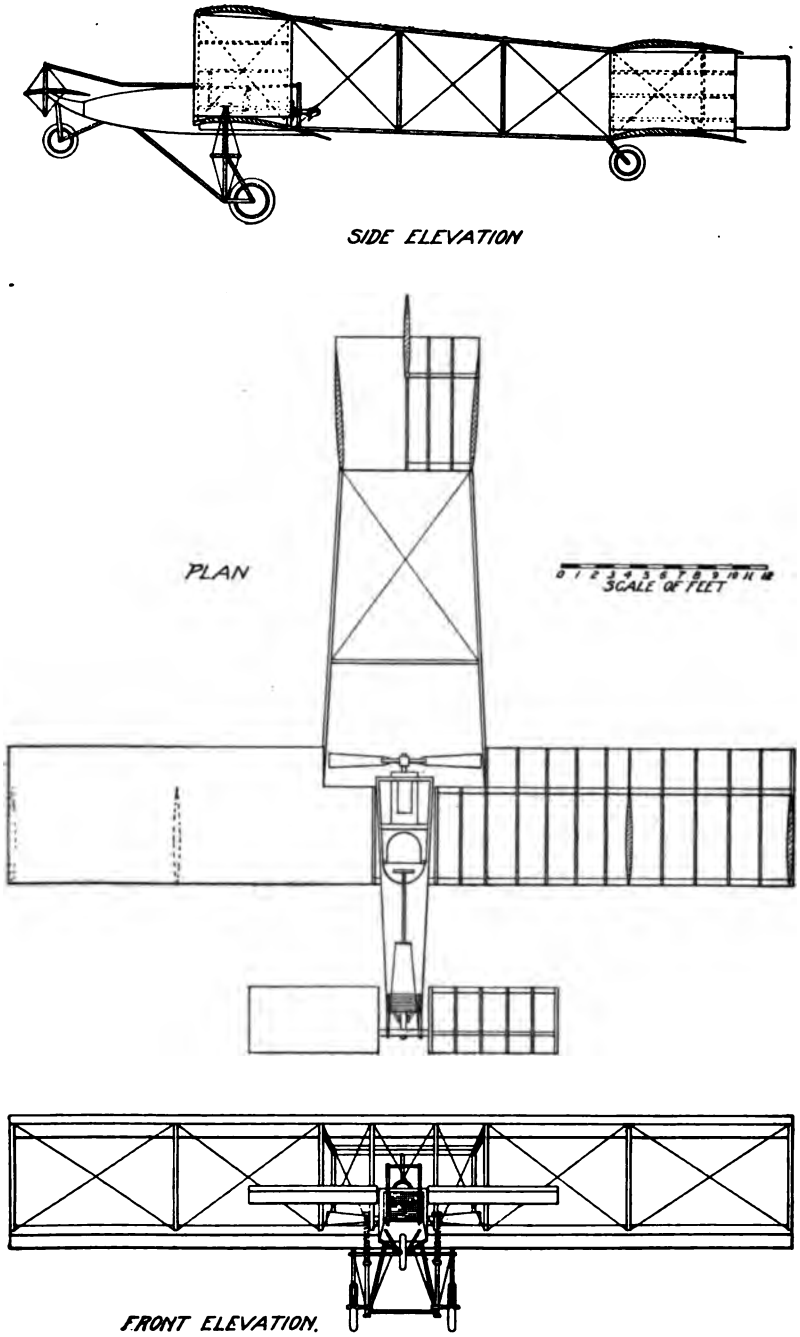


Fig. 18. Voisin Biplane with Vertical Keels

over ash ribs. Their form is rectangular. The spread is 37.8 feet, the depth 6.56 feet, and the total area 496 feet.

Direction Rudder. A single surface of 25 square feet area, placed in the center of the rear cells, is used for directing the machine. It is operated by means of a steering wheel and cables similar to those on a boat.

Elevation Rudder. The elevation rudder consists of a single surface of 41 square feet area situated at the forward end of the central chassis, and is controlled by a lever system attached to the axis of the steering wheel. By pushing out on the steering wheel, the rudder's inclination with the line of flight is reduced and the machine descends, the reverse action being obtained by pulling in. There is no operating mechanism employed for transverse control in the earlier Voisin machines, lateral stability being attained by the use of a number of keels which took the form of vertical partitions at regular intervals between the main planes, thus dividing the machine into a number of cells. This has recently been abandoned, however, in favor of the system of independent ailerons.

Power Plant. A 50- to 55-horse-power motor, placed on the rear of the central chassis and back of the main planes, drives a two-bladed metal propeller direct at a speed of 1,200 r. p. m., the propeller measuring 7.6 feet in diameter with a pitch of 4.6 feet. Several types of motors have been used.

General. The aviator's seat is placed on the central chassis in front of the motor and just back of the forward edge of the main planes. As a starting and landing chassis, two large pneumatic-tired wheels fitted with coil spring shock absorbers are fitted at the front and two at the rear. To avoid disastrous results, should the machine land at too sharp an angle, head-on, a small wheel is fitted to the front end of the chassis directly beneath the elevating rudder. The total weight is from 1,100 to 1,250 pounds, speed 35 m. p. h.; 23 pounds are lifted per horse-power, and 2.37 pounds per square foot of surface. The aspect ratio is 5.75 to 1. The use of the six vertical planes (two vertical walls of the rear cell and four vertical partitions between the two main supporting planes), Fig. 18, for steadying the machine transversely and keeping it to its course, are much lauded by Berget as superior to the Wright system of warping the planes, but experience appears to have proved to the contrary.

The Voisin type of biplane has recently been modified as follows: The vertical partitions have been done away with and ailerons are employed, together with a single plane, horizontal keel at the rear, instead of two planes. A 60-horse-power E. N. V. motor is employed, the total weight of the machine being about 1,170 pounds, giving a lift of 19.5 pounds per horse-power, and 3.27 pounds per square foot of surface. The aspect ratio is 5.13 to 1. This is a racing type of Voisin and is characterized by the elimination of most of the struts, cross wires, and other parts tending to increase the resistance to flight.

The regular Voisin biplane also has been altered by discarding the vertical partitions altogether, the design otherwise remaining the same. This machine has a spread of 36.1 feet, a depth of 6.56 feet, a total area of 430 square feet, and a weight of 1,350 pounds. The motor employed is an eight-cylinder E. N. V. of 60 horse-power, carrying 22.5 pounds per horse-power and 3.14 pounds per square foot of surface. The aspect ratio is 5.5 to 1. In some of the more recent Voisin machines the front elevating rudder also has been discarded, Fig. 19.

Fig. 19. Voisin Biplane in which Paris-Bordeaux Flight was Made

Voisin Tractor Screw. This machine, Fig. 20, was first built in the latter part of 1909, and embodies several totally new departures in the construction of biplanes. It did not meet with particular

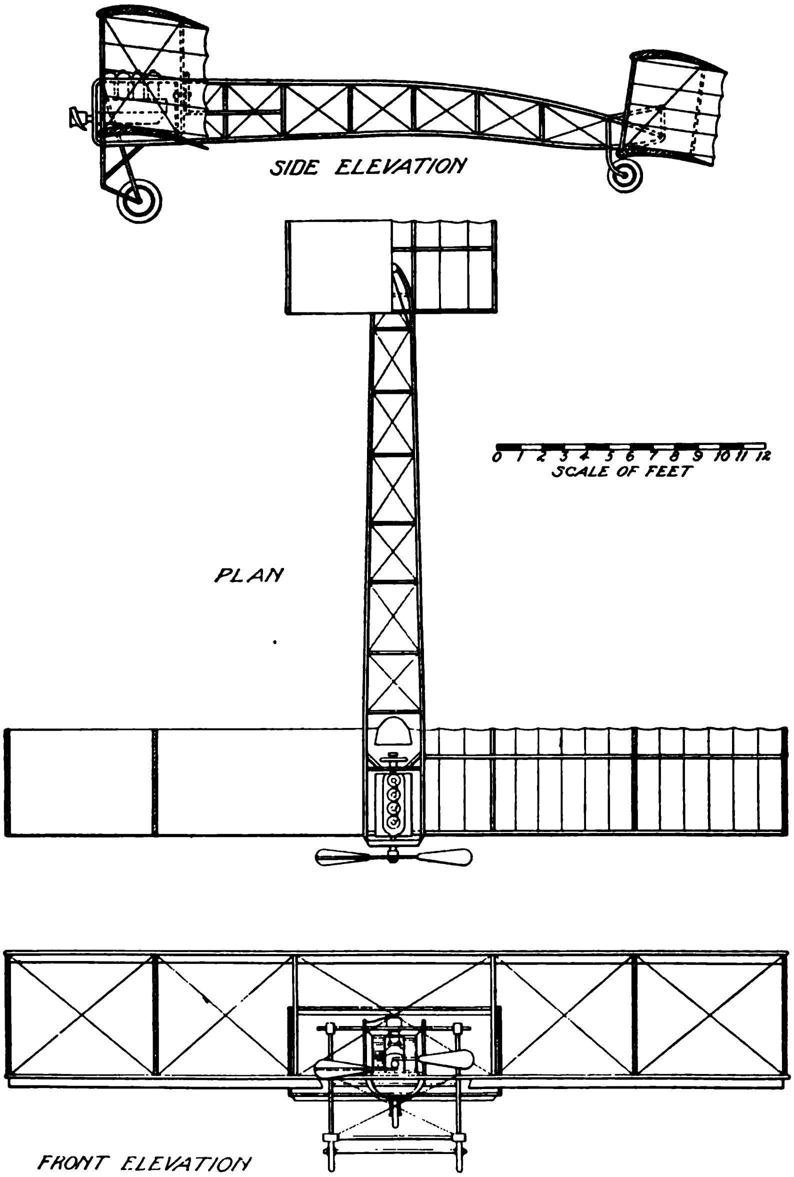


Fig. 20. Voisin Tractor Screw Type

success during 1910, although the Goupy and Breguet aeroplanes of the same type have been flown with great ease.

Frame. In this instance, the central chassis is extended a considerable distance to the rear, forming an "appendage." At the front are situated the motor and propeller, while directly behind the propeller is the main cell, with an auxiliary cell at the extreme rear. Ash, steel joints, and steel tubing are used throughout.

Supporting Planes. The supporting planes are two similar, directly-superposed surfaces with a spread of 37 feet, a depth of 5 feet, and an area of 370 square feet. By comparing the side elevations of the Voisin and Wright machines, the slight difference in the curvature of the planes, as well as their thickness, will be noted, though on comparing this feature in all of the machines illustrated, their striking similarity, as well as their close adherence to the pisciform contour of the plane—laid down by Colonel Renard as the most efficient shape for speed and stability—will be at once apparent.

Direction and Elevation Rudder. As these two elements are combined in the actual construction, they are accordingly described together. They are formed by the rear cell, consisting of two horizontal surfaces of about 80 square feet of area, and two vertical surfaces of about 50 square feet, the entire cell being pivoted on a universal joint so that it may be moved in any direction. The movement of the cell is controlled by cables leading to a large steering wheel in front of the aviator, the horizontal surfaces acting to elevate or depress the machine, and the vertical surfaces to change the direction of its travel. To ascend, the inclination of the cell relative to the line of flight is decreased, the leverage desired being the opposite of that necessary with a front elevation rudder. Four vertical partitions are placed between the main planes. There is no transverse control.

Power Plant. The power plant consists of a 40-horse-power, four-cylinder Voisin motor placed at the front end of the chassis and carrying directly on its crank shaft a two-bladed metal propeller 7.2 feet in diameter with a 4-foot pitch, which it drives at 1,300 r. p. m.

General. The chassis is mounted on two large pneumatic-tired wheels forward, fitted with shock-absorbing springs, and a smaller third wheel at the rear, while the aviator's seat is placed on the central frame at the rear of the main cell. The total weight is from

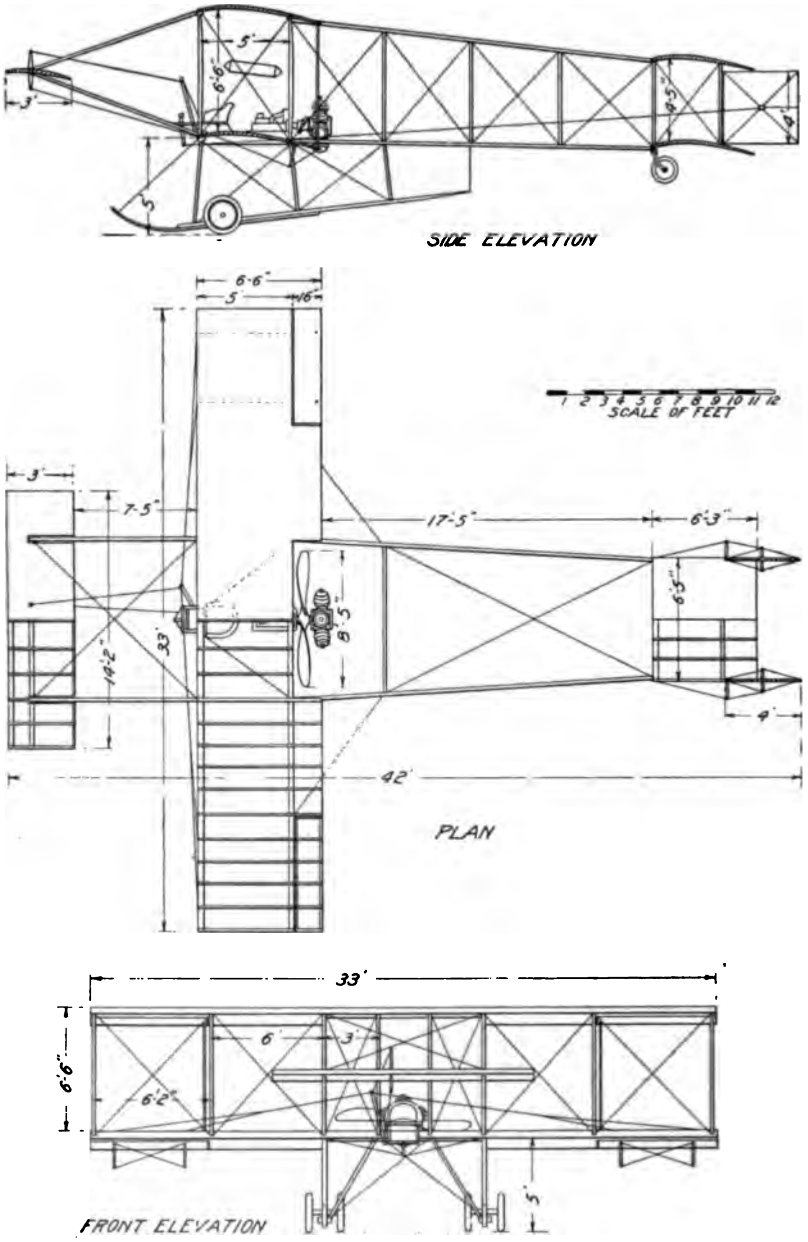


Fig. 21. Details of Farman III Biplane

800 to 950 pounds and the speed is said to be 50 miles an hour; 19 pounds per horse-power are lifted and 2.36 pounds carried per square foot of surface. The aspect ratio is 7.4 to 1.

Farman. The Farman machine, Fig. 21, has figured very prominently in the making of records and the winning of prizes, having been employed extensively by such aviators as Paulhan and White, as well as by Farman himself, Fig. 22. More than a hundred of the Farman biplanes had been built and put into use up to the end of 1910. It is a comparatively heavy type, and for a slow-moving, reliable machine it has proved very satisfactory.

Frame. The frame consists essentially of a main box-cell, somewhat similar in design to a Pratt truss, counterbalanced throughout with identical upper and lower chords, uprights of wood acting as compression members and cross wires as tension members, as is the case in all of the biplanes considered in this description of standard types. The supporting surfaces are analogous to the upper and lower decks of such a truss.

Supporting Planes. These supporting planes are practically identical with those of the machines already described, the surfaces themselves being made of continental cloth, stretched tightly over ash ribs. Their spread is 33 feet, depth 6.6 feet, and total area 430 square feet. The distance between the planes is 6.6 feet, which causes the machine to appear very much larger than the others by comparison and also gives it a very cumbrous look, the latter being accentuated by its very deliberate flight.

Elevation Rudder. The elevation rudder consists of a single, horizontal surface having an area of 43 square feet and is placed well out in front. It is hinged and braced to two sets of outriggers, firmly attached to the main cell, and is controlled by a large lever at the aviator's right hand. By pulling on this lever, the rudder is tilted upward and the machine rises, the method of control being almost instinctive and very easily acquired.

Direction Rudder. Two equal surfaces vertically placed, of an aggregate area of 30 feet, serve to control the travel of the machine. These surfaces move together and are operated by a pivoted lever on which the aviator rests his feet. By pressing so as to turn the lever to the left the machine alters its course in the same direction, the movement being transmitted to the rudder itself by cables.

Transverse Control. The control of the lateral equilibrium, *i. e.*, the tipping from side to side, is effected by the use of ailerons or "wing tips" consisting of four flaps constituting the rear ends of each plane. The operation of these wing tips is brought about simultaneously with that of the direction rudder through an arrangement identical with that on the Wright biplane, *i. e.*, a lever which may be moved in any direction, its forward and back motion actuating the rudder, while a sidewise movement operates the wing tips, from which it will be apparent that they are merely a modification of the Wright idea. This lever is connected by wires to the lower flap on each side and they are interconnected in the same manner with the flaps above them. When the machine is standing still the flaps merely hang loose and the wires relax, but when in flight the wind keeps them out and the wires are taut so that they may be controlled by the lever. The extra resistance these flaps or ailerons create is probably responsible in large measure for the decreased speed of the machine.

Keels. Two horizontal surfaces at the rear act as keels. Their combined area is about 80 feet, but as their angle of incidence is low the lift they exert is small, their only function being to steady the machine longitudinally.

Power Plant. The power plant consists of a 50-horse-power, seven-cylinder, air-cooled, rotary Gnome motor, mounted on a shaft at the rear of the lower plane. A two-bladed wood propeller of 8.5 feet in diameter by a 4.62-foot pitch is attached directly to it and revolves with the motor at a speed of 1,200 r. p. m.

General. The machine is mounted on two long skids forming part of the framework, similar to the Wright construction, and upon each of these skids is placed a pair of wheels. The latter are attached to rubber springs so that in starting the machine runs on them, but in alighting they give way, permitting it to slide on the skids. The total weight is from 1,100 to 1,350 pounds, the variation in this, as in every instance, being accounted for by the fact that it includes that of the aviator. The weight lifted per horse-power is 24 pounds, and 2.8 pounds per square foot of surface, while the speed is 37 miles per hour. The aspect ratio is 5 to 1.

New Models. In the foregoing, a description has been given of the original type of Farman biplane, numerous modifications

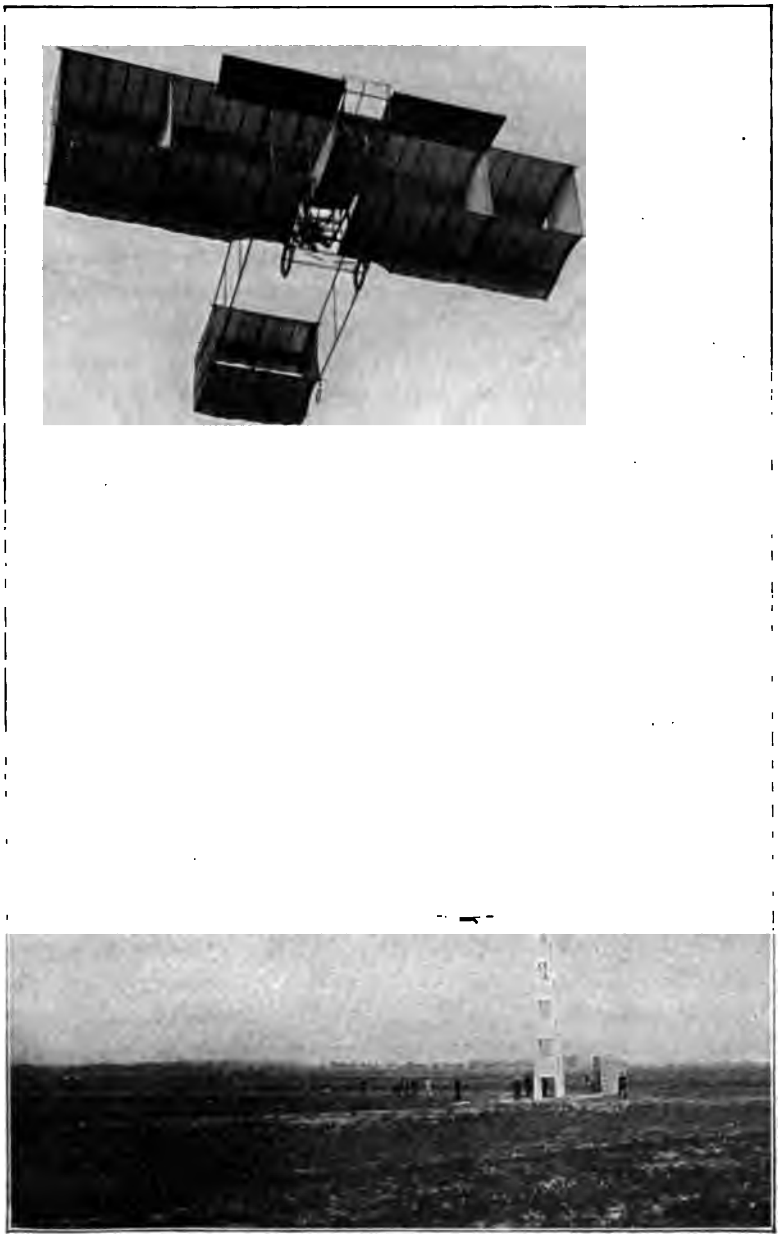


Fig. 22. Farman Biplane in Flight

having been made in more recent machines, Fig. 22. The latter, for instance, are fitted with a single-surface direction rudder, instead of the twin surfaces mentioned. The elevation rudder is kept in front, but is made smaller, and in addition the rear end of the upper of the two fixed, horizontal keels at the rear is made movable conjointly with the front rudder to control the elevation of the machine. In some cases, only a single surface is used at the rear. One wheel has been substituted for the two formerly employed, the other characteristics of the machine remaining substantially as described.

The new racing Farman biplane is distinguished by the following features: The spread is reduced to 28 feet and the area to 350 square feet, while the total weight in flight is about 1,050 pounds. The lift is 21 pounds per horse-power, while that per square foot is the unusually high figure of 3 pounds. The aspect ratio is 4.2 to 1.

Another more recent type of Farman is the huge, new passenger-carrying machine which made the first four-passenger record. This has a spread of 47.6 feet and an area of approximately 540 square feet. The maximum total weight is nearly 1,750 pounds, or close to a ton, thus giving a capacity of 34 pounds per horse-power and a loading of 3.15 pounds per square foot of surface. The aspect ratio is 7.1 to 1.

In a still later type of the Farman, the ailerons are let into the wings and while they are hinged they are not permitted to hang down, as was formerly the case, this innovation being responsible for a decided reduction in the head resistance. Another type, brought out at the end of 1911, shows an entirely new form of stabilizing surfaces. These take the form of two pairs of long planes, one at each end of the main planes, and with their narrow edge to the wind, giving them a very small aspect ratio, though they have a comparatively large area. Each pair is held apart by struts and they are mounted on a vertical shaft, which is turned to swing them outward. The construction of the main cell in this machine does not exhibit any departures from the regulation Farman form, but in the machine with the set-in ailerons, which also made its debut at the Paris Salon at the end of 1911, the planes are "staggered," *i. e.*, the lower plane is very much shorter than the upper, and they are connected by diagonal steel struts, thus doing away with the maze of wire braces. A single surface tail is employed in connection with front and rear elevators and twin vertical rudders.

The Maurice Farman biplane differs somewhat from the machines just described (Henri Farman), the two brothers having at first operated independently. It is noteworthy for its remarkable duration performances. It was in one of the Maurice Farman biplanes that Tabuteau broke the 1909 world's duration record of 244 miles in 5 hours 3 minutes 5 seconds, by traveling 290 miles in 6:8:12 (October 28, 1910), which he increased on December 30, 1910, to 365 miles in 7:48:31, thereby winning the Michelin cup. The same machine also won the $20,000 prize for the flight from Paris with a passenger to the Puy de Dome, a mountain 4,800 feet high and 235 miles distant. Numerous attempts had been made to win this during three successive years. The Farman biplane covered the distance in 5:10:46, including a stop of 14 minutes, the time limit in which the prize could be won being six hours, which included circling the Arc de Triomphe in Paris and the steeples of the cathedral at Clermont-Ferrand near the finish as part of the conditions. The machine has a supporting surface of 635 square feet and an aspect ratio of 8 to 1. Its weight is 1,210 pounds and with a 60-horse-power Renault, eight-cylinder, air-cooled motor its speed is 48 miles per hour. The propeller is driven from the cam shaft instead of the crank shaft, so that at a motor speed of 1,800 r. p. m., it makes 900 r. p. m. Maurice Farman was the first to employ a covered body enclosing the seats and the engine, this construction now being considered essential for the comfort of the pilot and passenger on all Continental aeroplanes, though up to the beginning of 1912, it had not been made a feature of any of the American machines. The Farman control is very simple and effective. It consists of a hand wheel on a sliding shaft and a pair of pedals. Forward and backward motion of the wheel controls the angle of the elevator, while rotation of the wheel operates the rudders, the pedals actuating the ailerons. The wheel is vertical, its shaft passing horizontally through an automobile type of dash on which are mounted a clock, a gradient indicator, an aneroid barometer, and a recording barograph.

Sommer. In June, 1909, Roger Sommer purchased a biplane constructed by Henri Farman (the machine of Maurice Farman differs in design) and on July 3 he made his first flight. Scarcely a month later he held what was then the world's record for duration

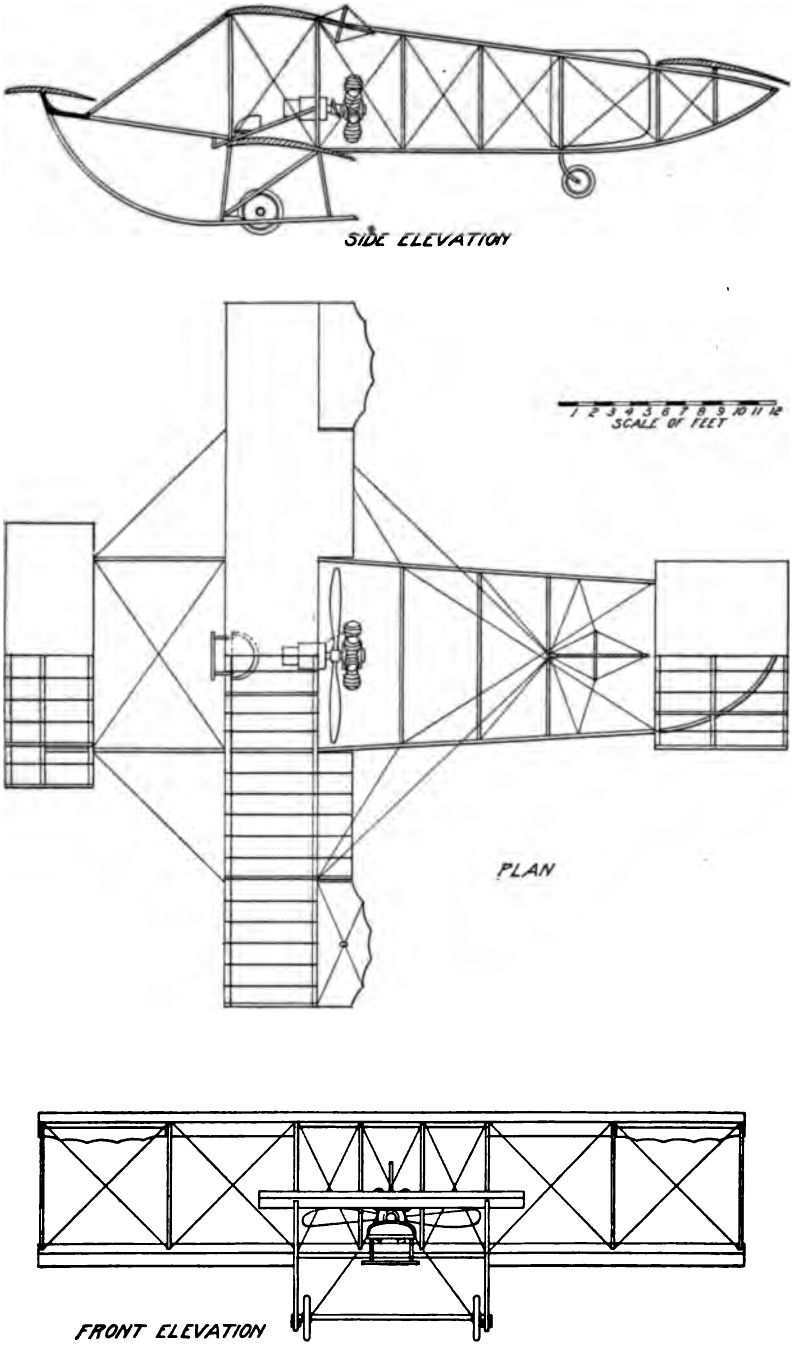


Fig. 23. Details of Sommer Biplane

of flight, having flown continuously for two and one half hours. His sudden jump into the ranks of the great aviators was remarkable and showed that, after all, it is not so hard to learn to fly well. He won many prizes at Rheims and Doncaster in 1909, but shortly afterward gave up flying on the Farman biplane and proceeded to design and build one of his own, Fig. 23. This was first tried out in January, 1910, and after a few days of experimenting he succeeded in making a long cross-country flight. The Sommer biplane is also operated by other prominent French aviators.

Frame. The construction of the frame is chiefly of hickory and ash with steel joints and steel tubing, its general character and appearance being similar to that of the Farman.

Supporting Planes. Two identical and directly-superposed rigid planes carry the machine, the surfaces being made of rubber cloth covering wood ribs. The sectional curvature of the surfaces is not so highly arched as in most other types, being more nearly, as in the Wright machine, a very even and gently sloping curve. The spread of the planes is 33 feet, their depth 5.2 feet, and their area 326 square feet.

Elevation Rudder. At a distance of 8.25 feet in front of the main cell, and supported on framing carried down to the skids, is placed the single-surface elevating rudder. This is governed by a large lever held in the aviator's left hand, which, when pushed out, turns down the rudder and, when pulled in, turns it up; thus, respectively, causing the aeroplane to mount or descend.

Direction Rudder. The direction rudder consists of a single surface of but 10 square feet in area, placed at the rear. It is operated by a pivoted foot lever similar to that of the Farman.

Transverse Control. Lateral equilibrium is secured by two wing tips, one placed at either end of the rear of the upper plane, as shown clearly in Fig. 24, there being no ailerons on the lower main plane as in the Farman. These are controlled by cables leading to a brace attached to the aviator's body. By leaning to the right, the wing tip on the left is pulled down, at the same time pulling up that on the right, causing the left end of the machine to rise and the right end to descend. Though not interconnected, the direction rudder and the transverse control are operated simultaneously by the operator, thus giving the same effect as is obtained in the Wright and

Farman machines by controlling these two elements from the same lever.

Keels. A single horizontal plane of 55 square feet area and of very light construction is placed at the rear and steadies the machine longitudinally. This plane is movable though it does not act as a rudder. A lever at the right hand of the operator, which automatically locks in place, enables the angle of incidence of this surface to be varied at will, thus increasing the attainable stability.

Power Plant. The power plant consists of the same type of rotary, air-cooled, seven-cylinder Gnome motor as employed on the Farman. It is placed at the rear of the main cell and is attached to a two-bladed wood propeller of 7.2 diameter by a 5.2-foot pitch, which it revolves at 1,200 r. p. m.

Fig. 24. Sommer Biplane Equipped with Gnome Seven-Cylinder Motor

General. Two large wheels are attached forward and two small wheels at the rear of the chassis, the front wheels being held by rubber springs to two skids, built under the frame. The skids themselves are attached to the main frame by uprights, the joints being made of a springy sheet of metal bolted to the framing. This adds still further to the resilient character of the mounting. The seat for the aviator is placed on the front of the lower main plane at the center and is fitted more comfortably than on most other biplanes which had been built up to that time.

In more recent machines for racing purposes the two end panels of the lower surface of the Sommer have been eliminated, reducing the spread and cutting the area down to 256 square feet. The loading is 3.25 pounds per square foot.

Cody. Colonel Cody, an American, for a long time resident in England, is doubtless best known in this field through his connection with the successful operation of man-carrying kites several years ago. His work in this line for military scouting attracted considerable attention in England. In 1907, he commenced work on an aeroplane of huge dimensions, Fig. 25. At first, the tests of this machine were very disappointing, but by his remarkable perseverance Colonel Cody turned failures into successes and finally, in the late summer of 1909, accomplished a superb flight of over an hour, establishing what was then the world's record for cross-country flight. The machine has been altered a number of times, and in its form as settled upon in the spring of 1910, Fig. 26, was the largest successful aeroplane in use.

Fig. 25. Cody Biplane Ready for Flight

Frame. Bamboo is employed extensively throughout the frame but all joints are wound with steel wire. In addition, there are a number of upright members of ash. At the center several members

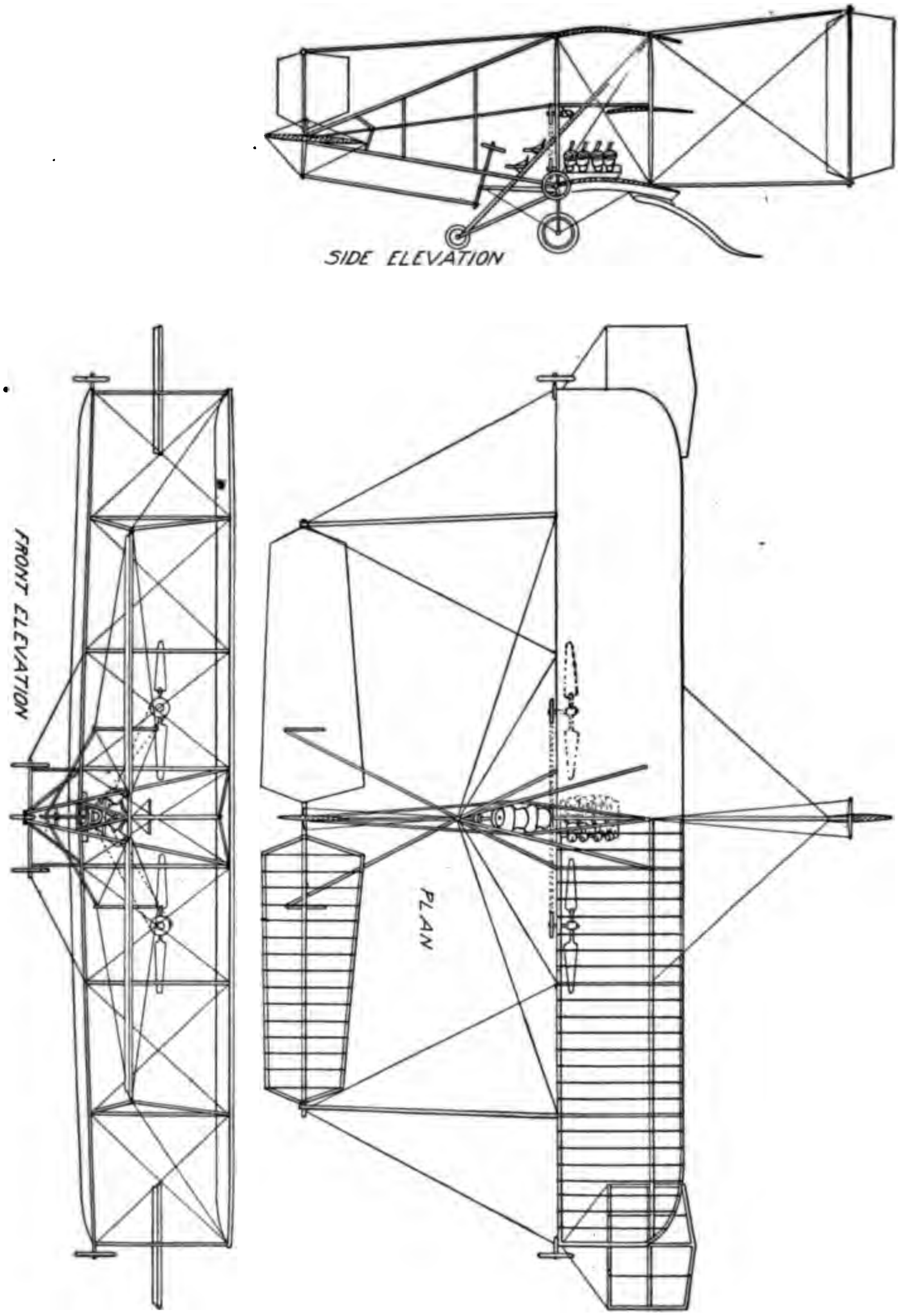


Fig. 26. Details of Cody Biplane

meet in the supporting chassis which is very heavily built. Steel wire is used for bracing.

Supporting Planes. The main planes are of rectangular form with rounded rear edges. They are identical and directly superposed, the surfaces being made of canvas tightly stretched over wood ribs. At the center, the distance between them is 9 feet, but they converge slightly toward either end where they are separated by only 8 feet. The spread is 52 feet, the depth 7.5 feet, and the area 780 square feet.

Elevation Rudder. At the front of the machine, supported by large bamboo outriggers from the central cell, are two equal surfaces placed on either side of the center. They are jointly movable and serve to control the elevation of the machine. They are governed by the forward or backward movement of the stanchion to which the steering wheel is attached, in the same manner as on the Curtiss. If the aviator wishes to rise, he pulls the wheel toward him. This motion, by means of a lever system, causes the elevating rudder surfaces to be tilted upward to the line of flight and the machine ascends.

Direction Rudders. Two direction rudders are employed, a large one at the rear and a small one in front, the former constituting the main rudder. These rudders are moved together by a steering wheel and cables as in a motorboat. Their combined area is about 40 square feet.

Transverse Control. Two balancing planes of 30 square feet area, one placed at either end of the main cell, control the transverse inclination of the machine. They are moved inversely by cables leading from the steering gear and operate in the same manner as the ailerons of the Curtiss machine and the wing tips of the Farman and Sommer biplanes, one balancing plane being turned up while the other is turned down. Lateral stability is also controlled by the inverse movement of the two halves of the elevation rudder, the one on the depressed side being elevated while the other is turned down. There are no keels on the Cody biplane, all surfaces serving either to lift or direct the machine.

Power Plant. The power plant is an eight-cylinder, 80-horsepower E. N. V. motor placed near the forward edge of the lower main plane and directly back of the aviator. It drives two two-bladed wood propellers mounted on shafts located at their front end half way between the main planes. These are driven in opposite directions by means of chains, as in the Wright biplane. These propellers have a diameter of 8.25 feet and a pitch of 6 feet; and are revolved at 600 r. p. m.

General. The mounting consists of a large pair of wheels which carry most of the weight, a small wheel in front and a skid at the rear. Wheels are also attached to the outer ends of the lower plane to carry the machine easily over the ground should it alight on end. The total weight is from 1,900 to 2,100 pounds; speed 37 miles per hour; 25 pounds per horse-power are lifted and 2.57 pounds per square foot of supporting surface. The aspect ratio is high—7 to 1. Seats are provided for the aviator and for one passenger, both being placed low at the center of the front of the main cell, that for the passenger being higher than that for the aviator, as it is designed for the use of an observer in war time.

Since the machine was first built, the E. N. V. motor has been replaced by two 50-horse-power, four-cylinder Green motors, both driving a single propeller instead of the twin propellers formerly used. Either motor can be operated independently, the advantage of this arrangement being that if one motor breaks down while in flight the other can still be used to drive the machine.

MONOPLANES

Antoinette. Up to the time of the present writing, the Antoinette, Fig. 27, is the largest monoplane in use and its construction is distinguished by a number of features not found on others. Levavasseur, designer of the Antoinette motor and motorboats, is credited with the design of this type. After building some experimental machines, notably the Gastambide-Mengin monoplane, the Antoinette IV was built for Hubert Latham. This machine was at first controlled transversely by means of wing tips, but the warpable surface, or Wright control, has since been adopted. The Antoinette is remarkably well built from an engineering standpoint and has been successfully operated by M. Latham in high winds, though not as strong as the gale in which the two Wright biplanes were blown backward 30 and 40 miles from Belmont Park at the International Meet, despite all they could do. The Antoinette is also flown by other prominent French aviators and several of the machines have been purchased by the French War Department.

Frame. The frame is of long, narrow, girder-like construction, Fig. 28, of cedar, ash, and aluminum, carrying at its forward part the main plane, the "nacelle" or car for the aviator, and at its extreme front end the propeller, while at the opposite end are placed the rudders, the longitudinal dimensions of the machine being in excess of 36 feet, or almost three fourths as much as its spread. The arrangement of the planes and rudder, as well as the location of the motor, is similar to that in all the monoplanes described here with the exception of the Pfitzner.

Supporting Plane. The supporting plane consists of a single surface divided in half, the two sections being of trapezoidal shape, placed at a slight dihedral angle to each other. They are constructed of rigid trussing, nearly a foot thick at the center and covered over and under with a smooth, finely-pumiced silk. The plane is also braced from a central mast. The spread is 46 feet, the average depth 8.2 feet, and the surface area 370 square feet.

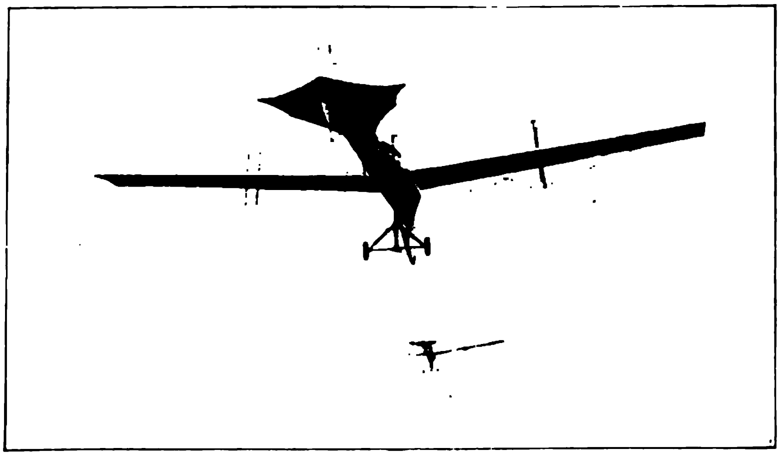


Fig. 27. Two Antoinette Monoplanes Competing at Belmont Park, 1910

Direction Rudder. The direction rudder consists of two vertical triangular surfaces at the rear and measures 10 square feet in area. These surfaces are moved jointly by means of wiring cables worked by a lever operated by the aviator's feet. When this lever, which moves in a horizontal plane, is turned to the left, the machine will change its course in the same direction.

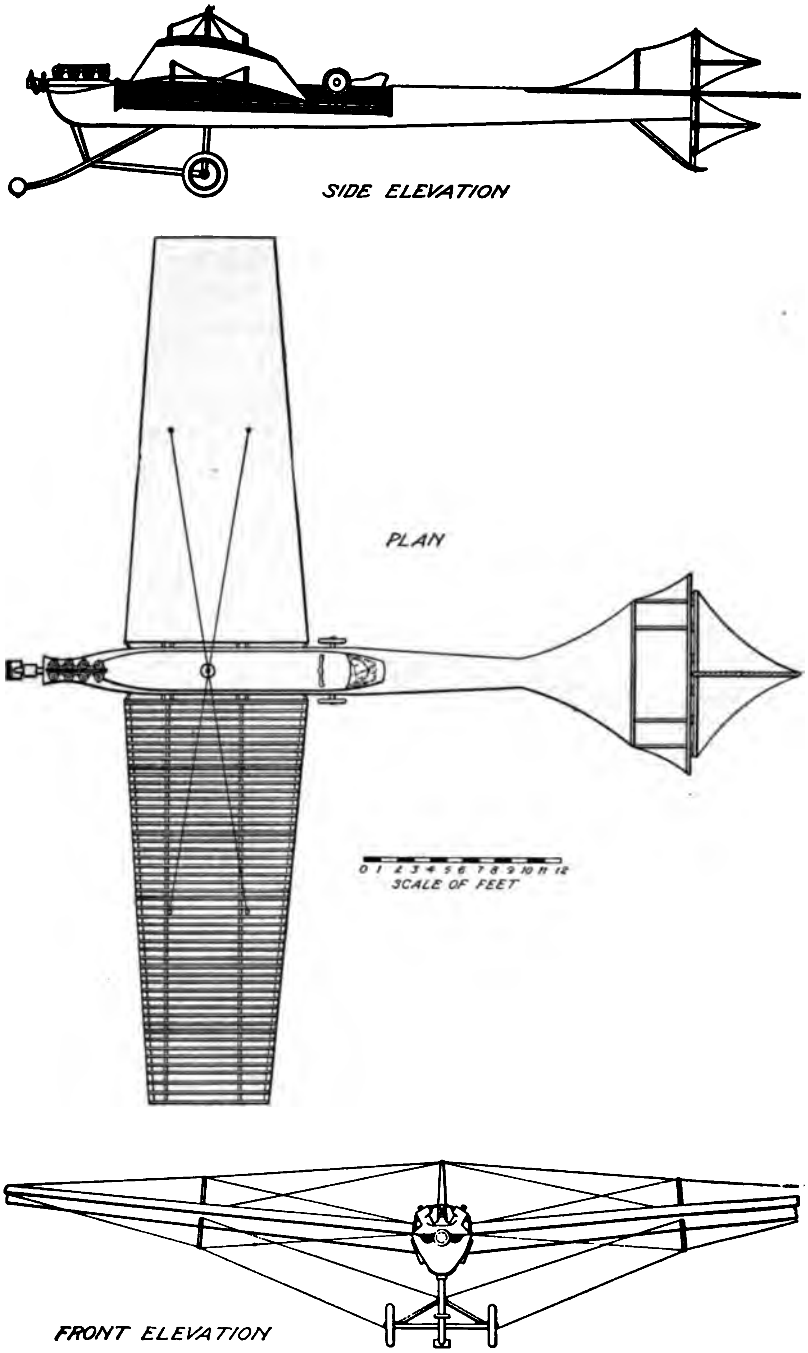


Fig. 28. Details of Antoinette Monoplane

Elevation Rudder. The elevation rudder has an area of 20 square feet and is also triangular. It is placed at the extreme rear in order to provide the maximum leverage, and is controlled by cables leading round a drum attached to a wheel at the aviator's right hand. To ascend, the wheel is turned up. This causes the inclination of the elevating rudder with regard to the line of flight to decrease, and the machine, therefore, rises.

Transverse Control. Lateral stability is maintained by warping the outer ends of the main plane in much the same manner as in the Wright machine, except that the front ends of the plane are movable and the rear ends are rigid throughout in the Antoinette, the reverse being the case in the Wright. Through cables and a sprocket placed at the lower end of the central mast, the warping is controlled by a wheel at the aviator's left hand. To correct a downward inclination at the right, the right end of the wing is turned up and at the same time the left end is turned down, restoring the balance.

Keels. At the rear, leading up to the rudders, are tapered keels, both horizontal and vertical, that add greatly to the bird-like appearance of the Antoinette in flight.

Power Plant. The power plant is an eight-cylinder, V-type, four-cycle, water-cooled Antoinette motor of 50 horse-power, the radiator taking the form of two banks of tubes placed along either side of the car. The motor carries on the forward end of its crank shaft a two-bladed, metal propeller, 7.25 feet in diameter by 4.3 feet pitch, which it drives at 1,100 r. p. m.

General. The chassis is mounted on a pair of pneumatic-tired wheels attached to the central mast by a pneumatic spring. In addition, a single skid is placed forward to protect the propeller in landing, and another at the rear. The seat for the aviator is placed in the frame back of the main plane and about 8 feet directly behind the motor, a seat for a passenger being provided in front of and slightly lower than that for the aviator. The sides of the space are walled with canvas, affording the aviator and passenger more protection than is usually provided. The total weight is 1,040 to 1,120 pounds, the speed 43 miles per hour. Thirty pounds are lifted per horse-power and 3.96 pounds per square foot of supporting surface. The aspect ratio is 6 to 1.

In a later machine, the spread is 49.3 feet, the area 405 square feet, and the total weight 1,200 to 1,350 pounds, 27 pounds being lifted per horse-power, and 3.33 pounds per square foot of surface. The aspect ratio is 6 to 1. A new 100-horse-power type is also employed for racing, this machine being fitted with the Antoinette sixteen-cylinder, V-type motor. The newer models of the Antoinette differ so radically that they have been described in the article devoted to special types.

Santos-Dumont. The first sustained flight of a motor-driven aeroplane in Europe was made by M. Santos-Dumont on November 12, 1906, in a biplane of his own design, Fig. 29. In 1907 he began work on a monoplane and after a great deal of experimenting succeeded in evolving the Demoiselle, Fig. 30, so-called owing to its diminutive size, as it is the smallest aeroplane in use up to the present writing. It is extremely simple and compact and many of them are flown abroad. Some of Santos-Dumont's earlier attempts were based on principles attractive in theory, but which experience has

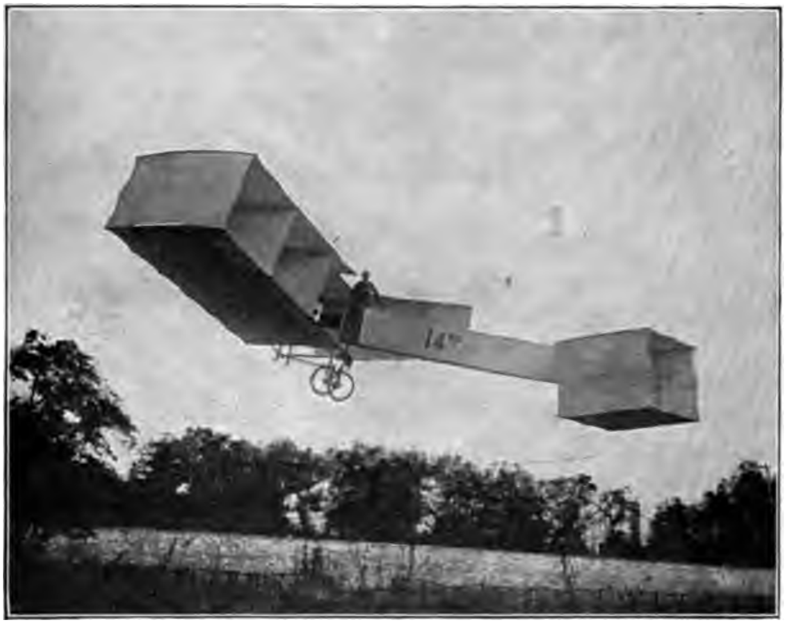
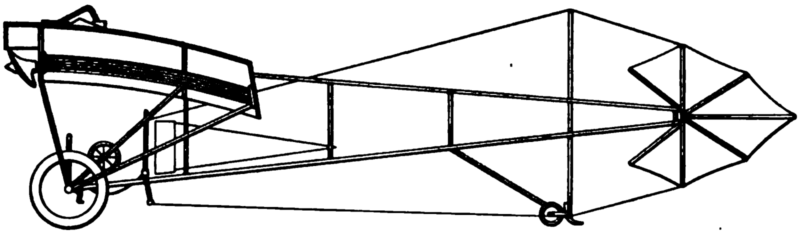


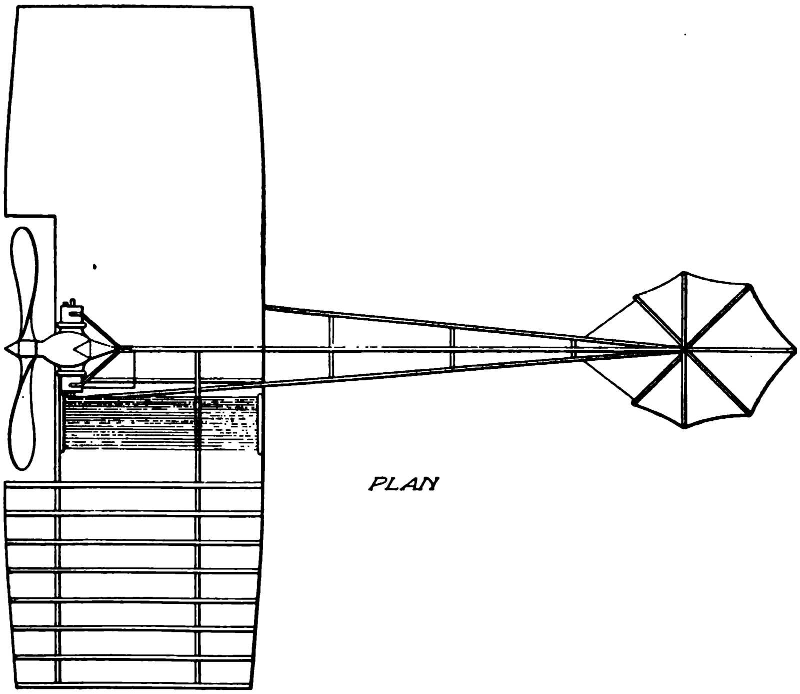
Fig. 29. Santos-Dumont's Earliest Aeroplane with Which He Made the First Power Flight in Europe

shown to be erroneous. Chief among these are the use of a sharp dihedral angle for the supporting surfaces and a very low center of gravity to simulate a pendulum. As shown by the Wright Brothers' experiments, while a pendulum may give a certain stability in a state of perfect rest or when flying straightaway in a dead calm, it exaggerates oscillation, once the latter is set up, and is entirely destructive of stability. Planes set at a dihedral angle give neither the same lifting power nor an amount of stability equal to a surface of the same dimensions that is made perfectly flat laterally. This is the case in all the biplanes described here and some of the monoplanes, the supporting surfaces of the Bleriot and Antoinette being set at a slight dihedral angle, however. This characteristic is still strongly marked in the Santos-Dumont monoplane, but the motor has been placed on a level with the supporting surfaces. The lack of stability of this machine was very marked as compared with both the biplanes and monoplanes taking part in the International Meet near New York, both its pitching and rocking reaching extreme angles and continuing throughout the flight. When compared with the larger machines in the air, it appeared almost like a sparrow among eagles, and the difference in the character of their action in flight was also similar. At no time did Audemars or Garros leave the ground more than 30 or 40 feet below, when flying the Demoiselle monoplanes on the occasion in question.

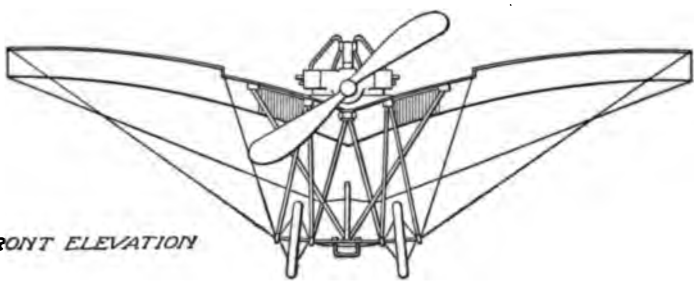
Fig. 30. Santos-Dumont Demoiselle, the Smallest Man-Carrying Aeroplane



SIDE ELEVATION



PLAN



FRONT ELEVATION

Fig. 31. Details of Santos-Dumont Demoiselle

Frame. The frame is triangular in form, Fig. 31, with its apex at the rear and is composed of bamboo with steel joints and several members of steel tubing.

Supporting Planes. Owing to the curvature of the supporting surfaces closely approximating the arc of a circle, there are really two planes joined at their inner ends. They consist of a double layer of silk tightly stretched over bamboo ribs, the whole being braced by steel wires led to the central frame. The spread is 18 feet, the depth 6.56 feet, and the area 113 square feet.

Direction and Elevation Rudders. The direction and elevation rudders are combined at the rear in the form of two fan-shaped surfaces, one vertical and the other horizontal, swung on a universal joint at the point of the triangular frame. The elevating rudder has an area of 21 square feet, while the direction rudder is somewhat smaller. A lever at the aviator's right hand controls the elevating rudder, while a wheel at the left operates the direction rudder. To ascend, the tail is moved up and to the right, to alter the line of travel in that direction. There are no keels.

Transverse Control. Transverse control is accomplished by warping the main planes, their operation being governed by a lever at the back of the aviator which fits into a pocket sewed into his coat. If the machine should suddenly tip up on the left, the aviator, by moving quickly in that direction, could pull down the plane on the right and increase the angle of incidence on that side. It will be seen from the foregoing that in flight he is kept pretty busy. The flexibility of the ribs of the planes permits them to warp without any special constructional details for that purpose.

Power Plant. A 30-horse-power, two-cylinder, horizontal-opposed water-cooled Darracq motor drives a two-bladed Chauviere wood propeller 6.9 feet in diameter by 6-foot pitch at 1,400 r. p. m., although Clement-Bayard and Panhard motors are also used on this machine.

General. The machine is mounted on two rigidly attached pneumatic-tired wheels at the front and a single small skid at the rear, the aviator's seat consisting of a strip of canvas placed across the frame and located directly beneath the motor. The propeller, instead of extending forward beyond the main planes, revolves in a rectangular opening cut in the latter. The total weight is from 330 to 370 pounds, speed 52 miles per hour. Twelve pounds are lifted

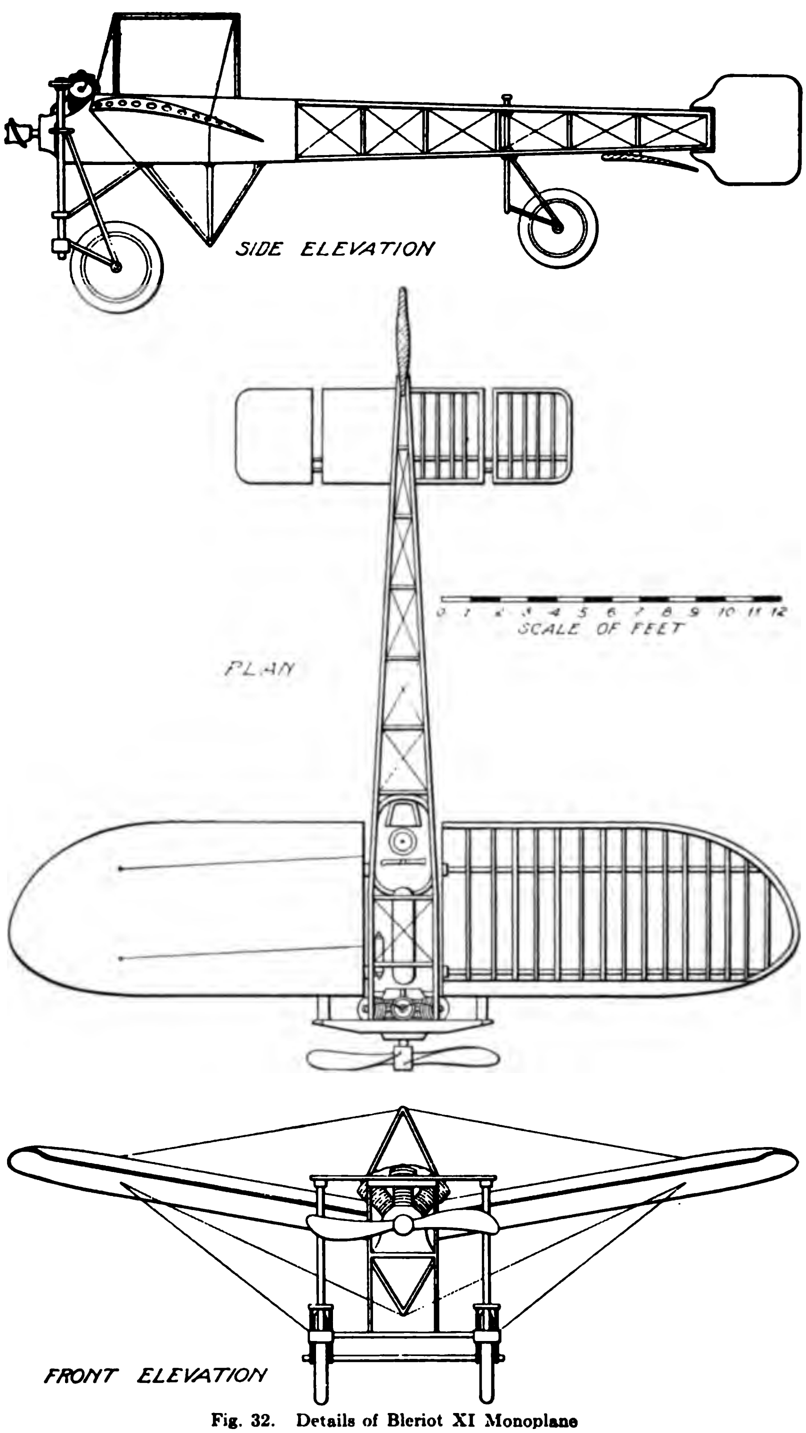


Fig. 32. Details of Bleriot XI Monoplane

per horse-power and 3.1 pounds per square foot of surface. The aspect ratio is 2.7 to 1.

Bleriot XI. In 1906, M. Louis Bleriot constructed and flew the first successful monoplane built. The two years following were devoted to experimental work, during which period a number of various modifications of the original were built until, in 1908, Bleriot succeeded in making a number of extended flights in his large monoplane, No. 8 Bis. In July, 1910, he made his sensational cross-channel trip, starting from Calais and landing near Dover. This flight was accomplished in the No. XI type machine, Fig. 32, a small one-passenger monoplane which is very simple and has come into widespread use abroad. Delagrange, Le Blanc, De Lesseps, Le Blon, Balsan, and Guyot are among some of the noted French aviators who have flown Bleriot monoplanes, two of whom have been killed in their operation. More than one hundred and forty of these machines were manufactured and sold during the year ending with August, 1910.

Frame. The frame consists essentially of a long central body of tapering construction to which the planes and rudder are attached. The framework is very lightly but strongly built of wood and is cross braced with steel wires throughout.

Supporting Plane. The main plane is placed at the forward part of the central frame and is divided in half, each section being mounted on either side of the central frame by socket joints. The halves are thus readily detachable at that point and when not in use are dismounted and placed in a vertical position along the frame so as to make the machine as a whole occupy very little room. The surfaces consist of wood ribs covered both above and below by Continental rubber fabric. The curvature is more pronounced than in most other types, with the exception of the Demoiselle, and a sharp front edge is obtained by the use of aluminum sheathing at that point. The two halves of the main plane are set at a slight dihedral angle. Their spread is 28.2 feet, depth 6.5 feet, and surface area 151 square feet. They are braced both above and below by steel wires led to the central frame.

Direction Rudder. The direction rudder consists of a very small plane having only 4.5 square feet of area and is placed at the extreme rear. It is controlled by a foot in the manner already described in some of the foregoing machines.

Elevation Rudder. The elevation rudder is divided into two parts, one half being mounted at each extremity of a fixed horizontal keel. It has 16 square feet of surface and is operated by the longitudinal movement of a bell crank device. This takes the form of a universally-pivoted lever placed in front of the operator, and is normally vertical. At the lower extremity of the lever is fixed a dome or hood-shaped piece of metal to which the wires are attached, at the same time protecting them from entanglement in the aviator's feet. To ascend the aviator pulls the lever toward him, and to descend pushes it from him.

Transverse Control. Lateral equilibrium is maintained by warping the main planes, the structure of the latter enabling them to be twisted as in the Wright machine, though in this case they warp about the bases which are rigidly attached to the main frame by the socket joints mentioned. The two halves are warped inversely by the side to side motion of the bell crank, *i. e.*, if the machine should tip up on the right, then the bell crank would be moved to the right. This would increase the incidence of the lowered side and at the same time decrease that of the raised side, thus righting the machine. The combination of this side to side movement of the bell crank with the movement of the foot lever controlling the direction rudder is used in turning.

Keels. To preserve the longitudinal stability, a single, fixed, horizontal keel is placed at the rear. Its area is 17 square feet.

Power Plant. The power plant is a three-cylinder, fan-shaped Anzani motor, developing 23 horse-power. It is of the air-cooled type and is placed at the forward end of the central frame. It drives a two-bladed wood propeller of 6.87 feet in diameter by 2.7-foot pitch direct at 1,350 r. p. m. Most of the more recent Bleriot monoplanes have been fitted with 50-horse-power Gnome, seven-cylinder, rotary, air-cooled motor.

General. The machine is mounted on an elastic chassis with two large rubber-tired wheels forward and a small wheel rear. The springs are made of thick rubber rope, affording great elasticity and strength with small weight. The aviator's seat is back of the main plane.

The total weight is from 650 to 720 pounds and the speed is 36 miles per hour with the Anzani motor and 48 miles per hour with the

Gnome motor; 29 pounds are lifted per horse-power and 4.5 pounds per square foot of surface, this ratio being unusually high. The aspect ratio is 4.35 to 1.

Later Types. In the later Bleriot machines, the elevating rudder is of different form, being attached at the rear edge of a tapering keel much larger than that formerly used. The small wheel at the rear has been replaced by a skid and the overall length of the central frame has been shortened considerably. The regular one-passenger type of this monoplane has further been altered to the new No. XI Bis, in which the sectional curvature of the planes has been made very nearly flat on the under side. This change has been found to greatly decrease the dynamic resistance of the machine without seriously impairing its lift. There are two new models of this machine which have been very successful. They are the No. XI 2 Bis, a two- or three-passenger machine, Fig. 33, and the No. XI racing model, Figs. 34 and 35. The former has a spread of 36 feet, a depth of 7.6 feet, a surface of 270 square feet, and a weight in flight of about 990 pounds. In other respects it resembles the No. XI Bis. 19.8 pounds are carried per horse-power and 3.68 pounds per square foot of surface. The aspect ratio is 4.75 to 1. The *type de course*, or No. XI racing model, is the machine on which Morane established the record of almost 69 miles per hour. It has a very short body, flat

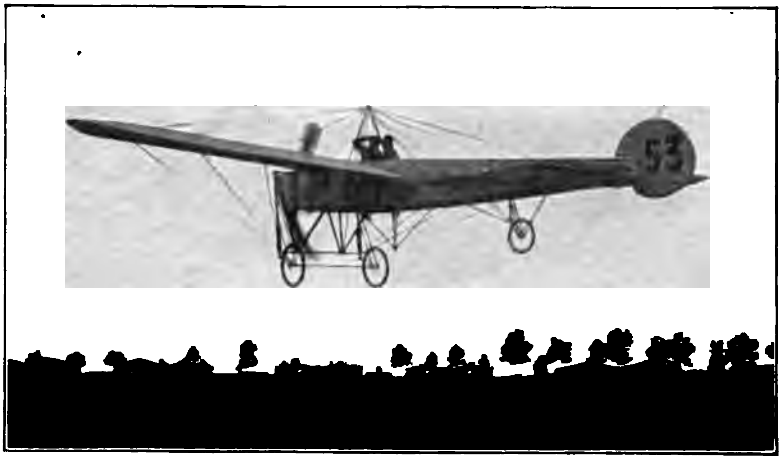


Fig. 33. Bleriot Two-Passenger Monoplane

planes, and a reinforced frame. The surface has been reduced to 129 square feet and it is equipped with one of the new 100-horse-power, fourteen-cylinder Gnome, rotary, air-cooled motors. The total weight is about 750 pounds; only 7.5 pounds are carried per horsepower and as much as 5.76 pounds are lifted per square foot of surface.

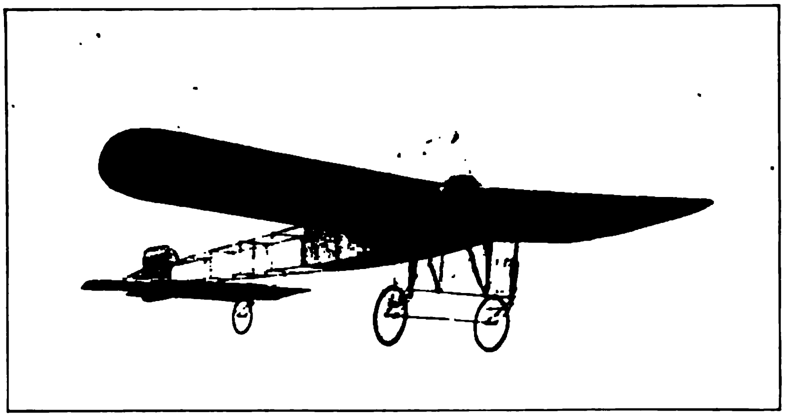


Fig. 34. Bleriot Racing Model in Flight

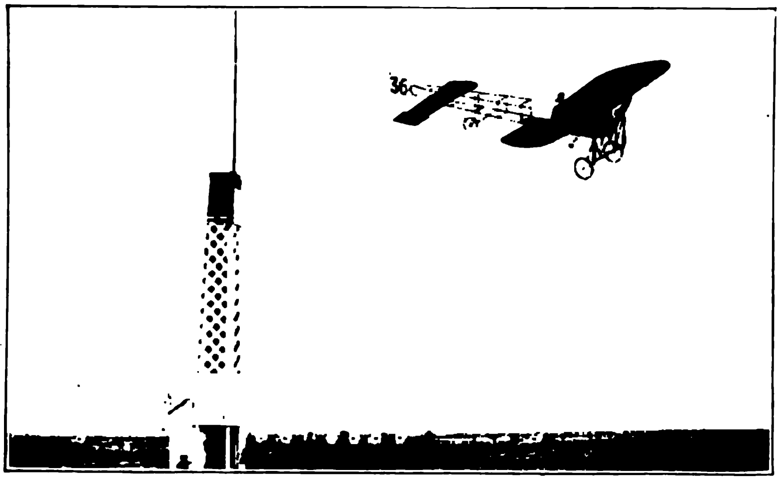


Fig. 35. Bleriot Rounding a Pylon in International Race for Gordon-Bennett Cup

Bleriot XII. The Bleriot XII is a passenger-carrying type which differs in construction from those just described. With one of these large machines, M. Bleriot made the first flight in an aeroplane carrying three passengers. It has since come into general use, more than thirty of them having been built.

Frame. The long central frame of wood, Fig. 36, braced in every panel by steel cross wires, is very deep forward and tapers gracefully to a point at the rear.

Supporting Plane. On the upper deck of the central frame at the front is placed the main plane which is continuous and perfectly horizontal. Its structure is similar to that of the No. XI and it is braced by a number of wires from the frame. The spread is 30.2 feet, the depth 7.6 feet, and the total area 228 square feet.

Direction Rudder. A single surface placed at the rear extremity of the vertical keel is used for this purpose. Its area is only 9 square feet and it is operated in the same manner as on the No. XI.

Elevation Rudder. The elevation rudder also consists of a single surface of 20 square feet area and placed at the extreme rear. It is operated by the movement of a bell crank, as already described.

Transverse Control. The main surfaces are warped inversely, exactly as in the No. XI, a small surface under the aviator's seat also assisting in the lateral balancing. A horizontal keel of 21 square feet area is placed on the framework at the rear, but somewhat forward of the elevating rudder.

Power Plant. The power plant consists of a 60-horse-power, eight-cylinder E. N. V., air-cooled motor, placed on the frame under the main plane. By means of a chain transmission it drives an 8.8-foot propeller mounted on a shaft at the edge of the main plane. The propeller has an unusually long pitch—9 feet—and turns at only 600 r. p. m.

General. The mounting is similar to that of No. XI, while the seat or bench for three persons is placed under the main plane and back of the motor. The total weight is from 1,150 to 1,300 pounds; speed 48 miles per hour; 21 pounds are lifted per horsepower and 5.3 pounds per square foot of surface. The aspect ratio is 4 to 1. Bleriot is one of the most prolific designers of monoplanes, and it would require a volume to describe them. The Bleriot Limousine or "aerial taxi" is described under special types.

Grade. Herr Grade has the distinction of being one of the first German aviators to design and build an aeroplane. In the fall of

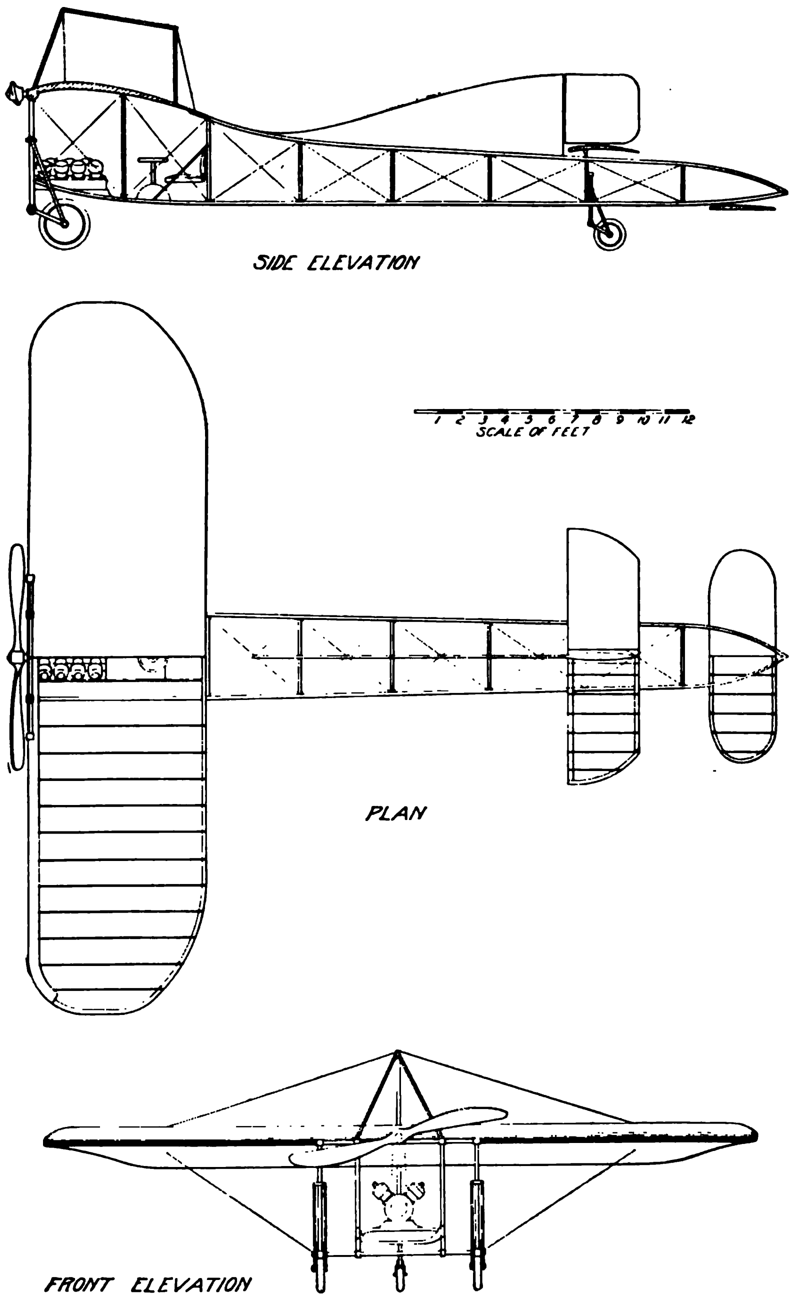


Fig. 36. Details of Bleriot XII Monoplane

1909, he began flights on his interesting monoplane, Fig. 37, and on October 30, 1909, won the Lanz $10,000 prize for a German-built machine. The machine is simple and flies easily. A number of them have already been built and sold in Germany.

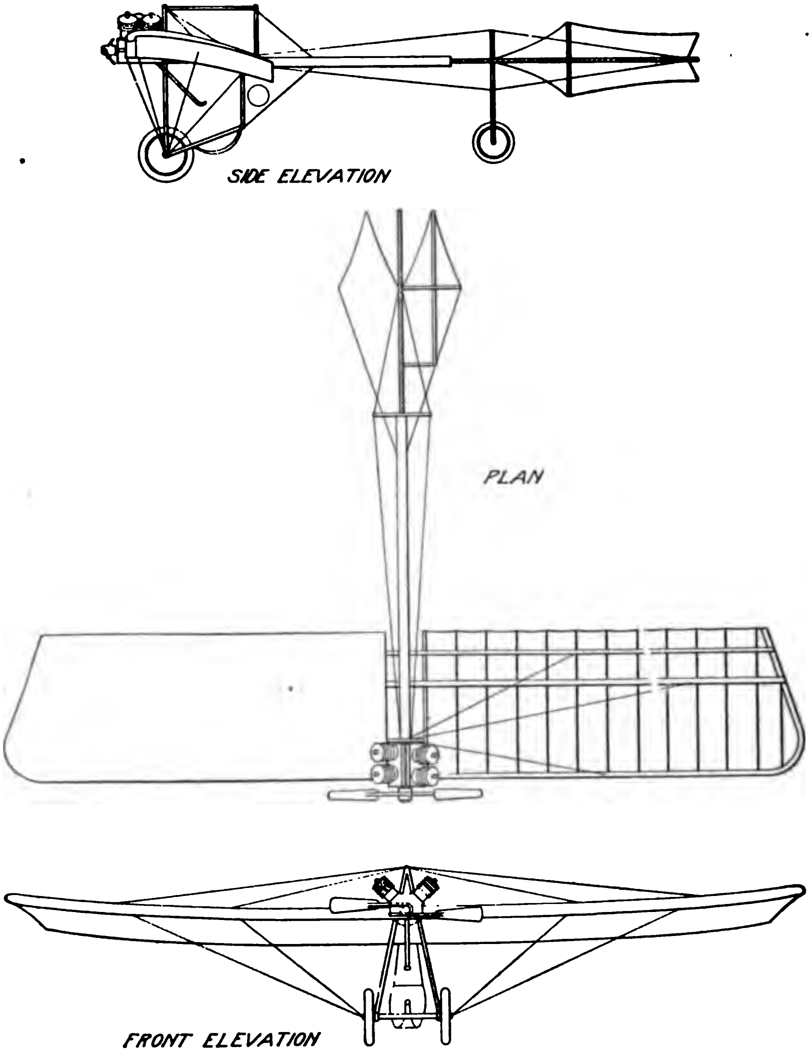


Fig. 37. Grade Monoplane, One of the Few German Aeroplane Designs

Frame. The frame is remarkable for the simplicity of its construction, consisting of a main metal tube chassis at the front from which a long thick member supporting the rudders is run out to the rear.

Supporting Plane. The main surface is made of Metzler rubber fabric stretched over a bamboo frame. The surface is very flexible and the two ends are turned up slightly from the center. The curvature is almost the arc of a circle and the section is very thin. The spread is 30 feet, depth 7 feet, and area 208 square feet.

Direction Rudder. The direction rudder consists of a single, flexible surface of 16 square feet area, carried at the rear and controlled by a lever. The surface itself is not hinged, but is bent in the direction desired by the lever and wire connections.

Elevation Rudder. The elevation rudder also consists of a single surface placed at the rear. It has an area of about 20 square feet and like the direction rudder its operation depends upon its flexibility. It is controlled by a large lever universally pivoted on the frame above the aviator. To rise, this lever is pulled up, and to descend, it is pushed down, thus bending up or down the rear horizontal surface.

Transverse Control. Warping the main planes is resorted to, the operation being similar to the Bleriot, which, in turn, is patterned after the Wright.

Keels. The tapering ends of both the direction and elevating rudders can be considered as keels, an additional vertical keel being placed forward, both above and below the main plane.

Power Plant. A four-cylinder, V-type, air-cooled motor of 24 horse-power is placed at the front edge of the plane. It drives direct at 1,000 r. p. m. a two-bladed metal propeller 6 feet in diameter by a 4-foot pitch.

General. Two wheels are employed forward and one rear for the mounting, no springs being provided. The front wheels are provided with a brake to bring the machine to a quick standstill after alighting, this being an important feature where the space is limited. The seat is placed under the main plane and consists of a hammock-like piece of cloth which is very light and very comfortable. The total weight is from 350 to 450 pounds and the speed approximately 44 miles per hour; 17 pounds are lifted per horse-power, and 1.9 pounds per square foot of surface. The aspect ratio is 3.2 to 1.

Pelterie. By many, the Pelterie monoplane, Fig. 38, is considered to be one of the most perfect types of aeroplane. Great care is shown in its construction and finish, but owing to motor troubles, it has never flown for any length of time. Its designer,

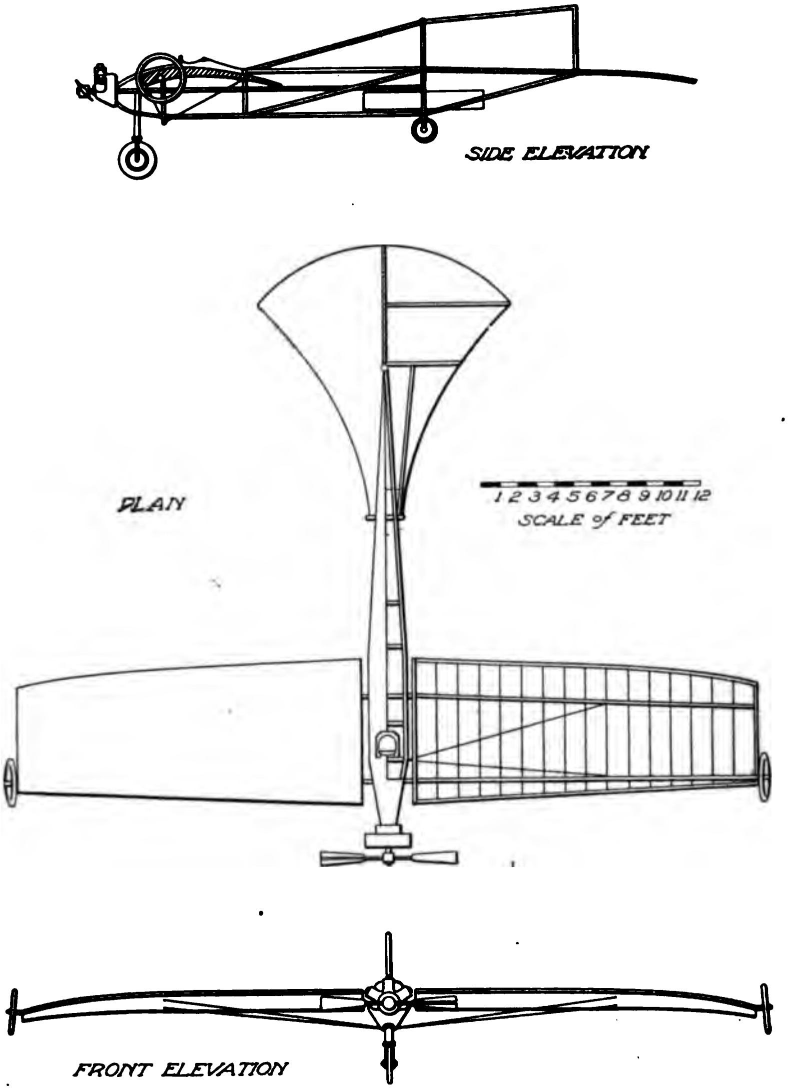


Fig. 38. Pelterie Monoplane

Robert Esnault Pelterie, is one of the foremost French aviation scientists, and previous to building this machine, he conducted a lengthy series of gliding experiments of considerable interest.

Frame. The central frame, somewhat similar in form to a bird's body, is made largely of steel tubing and is quite short. All exposed parts are covered with Continental cloth.

Supporting Plane. The main supporting surface is particularly strong and solid, being made of steel tubing carrying wood ribs covered with Continental cloth. The curvature is very similar to that of a bird's wing, and transversely the surface curves downward, dihedrally from the center. Very little bracing is necessary. The spread is 35 feet, depth 6.1 feet, and the area 214 square feet.

Direction Rudder. The direction rudder consists of a vertical rectangular surface of 8 square feet area placed below the central frame at the rear. It is operated by a lever at the aviator's right.

Elevation Control. There is no elevation rudder in the Pelterie monoplane, the elevation of the machine being accomplished by changing the angle of incidence of the main planes themselves. To ascend, for instance, the aviator pulls the lever in his left hand toward him. This increases the angle of incidence of the plane and accordingly increases the lift, causing the machine to rise.

Transverse Control. Each half of the main plane is warpable about its base, transverse equilibrium being maintained by the inverse warping of the planes in the usual manner. In turning, both the left-hand lever controlling the warping planes and the right-hand lever controlling the direction rudder are simultaneously moved to the side desired. It is worthy of note here, that of all aeroplanes employing the Wright system for maintaining lateral stability—and there are very few that do not—none of them combines the control in one lever in the same ingenious manner as found in the Wright machine.

Keels. Vertical and horizontal keels consisting of gradually tapering surfaces are fixed to the frame and aid in preserving stability. The rear horizontal keel, shaped like a bird's tail, has an area of 20 square feet.

Power Plant. The power plant consists of a seven-cylinder, fan-shaped, air-cooled R. E. P. (Robert Esnault Pelterie) motor of very ingenious design. It is placed at the front and drives direct a four-bladed aluminum and steel propeller at 900 r. p. m. Its diameter is 6.6 feet and its pitch 5 feet.

General. The mounting consists of a large single wheel carried on a combined hydraulic and pneumatic spring at the center of the front, with a smaller wheel on the same center line at the rear. Wheels are also placed at the outer ends, or tips, of the supporting planes, so that when first starting to run along the ground, the machine is inclined. The seat is placed in the frame, and protected on all sides, the aviator's shoulders coming flush with the supporting surfaces. The total weight is from 900 to 970 pounds; speed 39 miles per hour; 27 pounds are lifted per horse-power and 4.4 pounds carried per square foot of surface. The aspect ratio is 5.75 to 1.

In a later model of the R. E. P. the fuselage is entirely of steel tubing connected by welded joints and the whole strongly trussed. Each wing is composed of two ash spars covered by red Continental rubberized fabric. The method of attaching the wings to the fuselage is a distinctive feature. In most monoplanes the ends of the spars are let into the fuselage, but in this case they are attached to the body by means of joints. This prevents the portions of the wings near the fuselage from having to endure abnormal stresses due to their attachment in case the supporting stays should become slack. This arrangement also permits the dihedral angle between the wings to be varied slightly. The lower stays of the rear spar are attached to an oscillating lever mounted on ball bearings and controlled by the wing-warping lever, while the lower stays attached to the front spar and supporting the wings in flight are steel cables covered with cloth. The tail fins, elevator, and rudder are demountable, being composed simply of steel tubing covered with fabric. The well-developed horizontal tail fins, being distant from the center of gravity, give great longitudinal stability to the machine. The elevator, which forms the prolongation of the horizontal empennage or tail, is divided into two parts by the rudder, forward of which is the vertical keel.

Pfitzner. The Pfitzner machine, Fig. 39, represents a radical departure from all other aeroplanes in some of its features, while it differs from other monoplanes in the placing of the aviator, motor, and rudders. It was built in the early part of January, 1910, by A. L. Pfitzner at the Curtiss factory in Hammondsport, New York.

It was the first to employ the comparatively simple and efficient method of transverse control by means of sliding surfaces, and while the first flights were short, largely due to the inexperience of the aviator, it is considered by many to be a very promising type, par-

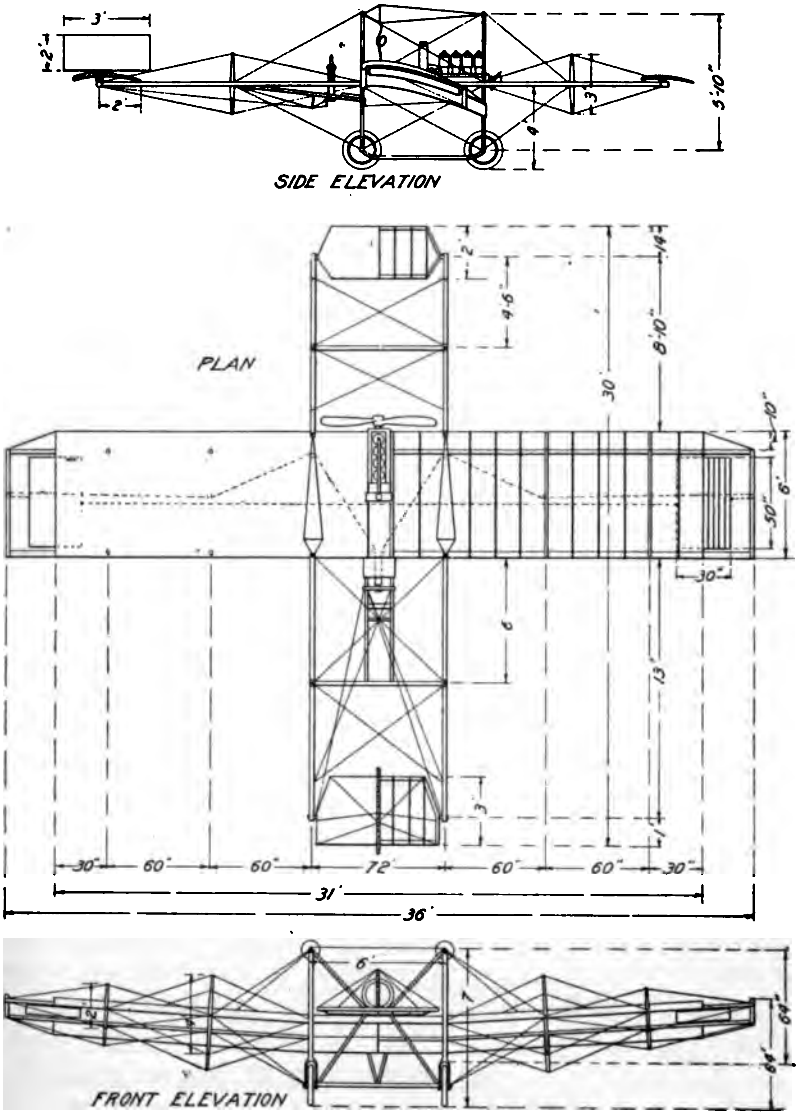


Fig. 39. Details of Pfitzner Monoplane

ticularly as it does not conflict with the Wright system in any way.

Frame. The framework is largely a combination of numerous king-post trusses with spruce compression members and wire tension members. The framework is open throughout, enabling quick inspection and easy repairs. At the center, the chassis is mainly composed of steel tubing.

Supporting Plane. The main supporting plane, a 5-degree dihedral angle, consists of two main beams, across which are placed spruce ribs. The surface is made of Baldwin vulcanized silk of jet-black color tacked to the top of the ribs and laced to the frame. The curvature of the surface is slight and is designed for high speed. The spread is 31 feet, depth 6 feet, and surface area 186 square feet.

Direction Rudder. The direction rudder is a rectangular surface of but 6 square feet in area and is placed at the front. It is operated by wires leading to the bracket underneath the controlling column. Turning this column to either side causes the machine to turn to that side.

Elevation Rudder. The elevation rudder is likewise placed at the front and is also a single surface of 17 square feet in area. It is operated by wires leading to a lever at the side of the controlling column. Moving the column forward or backward causes the elevation rudder to turn down or up, respectively.

Transverse Control. The framework of the main plane is carried out 30 inches beyond the end of the surface on either side and affords a place for a rail on which the auxiliary sliding surfaces move. These sliding surfaces, or equalizers, are each 12½ square feet in area and when "normal" project 15 inches beyond the end of the fixed surface on either side. They are interconnected by wires, and a long cable running to each end through a pulley connects them to the steering wheel. The control is as follows: If the right end of the aeroplane is tipped down, the wheel supported on the controlling column is turned away from the lowered side. This causes the equalizer on the raised end to be pulled in under the main surface, or "reefed," while at the same time the one on the other end is pulled out. This action merely decreases the surface on the raised end and increases it on the lowered end, thus righting the machine.

Keels. A horizontal surface placed at the rear acts as a longitudinal stabilizer. It is 10.5 square feet in area and is fixed firmly to the supporting framework, 10 feet to the rear of the main surface.

Power Plant. The power plant consists of a four-cylinder, air-cooled, 25-horse-power Curtiss motor placed on the framework above the plane and to the rear of it. The motor drives direct a two-bladed wood propeller 6 feet in diameter by 4.5 feet pitch at 1,200 r. p. m. This propeller is of original design and is said to be very efficient.

General. The machine is mounted on four small, rubber-tired wheels placed at the lower ends of the four main vertical posts of the chassis. They are spaced by steel tubing and are fitted with brakes, but have no springs. The seat for the aviator is placed out in front of the main plane and directly in the center line. The total weight in flight is from 560 to 600 pounds, while the speed is estimated at 42 miles per hour; 24 pounds are lifted per horse-power, and 3.2 pounds carried per square foot of surface. The aspect ratio is 5.7 to 1.

COMPARISON OF STANDARD TYPES

From the foregoing description of what has been termed standard types, it will be apparent that, while all have many features in common, no two are exactly alike in either design, constructional detail, or efficiency. Some that are less desirable from certain points of view than other types belonging to the same class, show an unusually high degree of efficiency; others have advantages of greater stability. All, however, have proved successful in operation and some to a far greater degree than others. It will accordingly be both interesting and profitable to note the contrasts and distinctions that may be drawn. From these it will be possible to arrive at conclusions as to what particular features are most desirable at present, as well as to note what the trend of the future may be. For this purpose the aeroplanes already described are compared according to the following essential features, which are given as nearly as possible in the order of their importance, where their influence on the result aimed at—flight—is concerned: (1) transverse control; (2) aspect ratio; (3) incident angle; (4) propellers; (5) rudders; (6) keels; (7) mounting; (8) speed; (9) flight; (10) efficiency.

The object of placing the factor of efficiency last in order of importance is not to indicate that as its actual position from the practical viewpoint, as this is the one thing that designers are now striving hardest to attain, but more because it represents the best opportunity to sum up generally the performances of the different machines. Motors are compared at the conclusion of the chapter on that subject.

Transverse Control. In practice, the lateral stability of aeroplanes is maintained by four different methods: (1) automatically; (2) by warping; (3) by balancing planes, *i. e.*, wing tips or ailerons; (4) by "reefing," or the employment of supplementary sliding planes or equalizers.

At present, warping the planes is the most generally employed and most practical method, but it is expected that a simple method of automatically preserving the lateral equilibrium will be the ultimate development, and many designers, including the Wright Brothers, are striving for that end, so that it is given precedence here.

The Voisin is the only type for which automatic stability has been claimed, but it is noticeable that in later types of this machine, wing tips have been employed. The rear box-cell and the vertical keels or partitions between the surfaces of the main planes exert such a forcible "hold" on the air that to displace the machine is difficult and, in all ordinary turmoils of the air, it displays exceptional stability. In fact, a well-known aviator amusingly stated at Rheims that, were a Voisin tipped completely over on one end, it would still be aerodynamically supported, so great is the expanse of vertical surface.

Without such keels, however, the lateral balance of an aeroplane is so precarious that some form of control is absolutely necessary. The method of warping the planes in connection with the operation of the vertical or direction rudder is the chief claim of the Wright patents, and all machines employing it are essentially the same as the Wright device, even though the operating connections do not control the main planes and the rudder simultaneously. In addition to the biplanes employing it, all the successful monoplane types, except the Pfitzner, depend upon warping the main planes for this control.

Because of the structural difficulty of rigidly bracing the surface of a monoplane, warping is an ideal form of control. But the rigid structure of the biplane permits auxiliary planes to be more easily provided. This is done in the Curtiss, Farman, Sommer, the recent

Voisin, and the Cody. Both these methods of transverse control are very efficacious, but the additional resistance, unaccompanied by any increase of lift, which is produced by balancing planes, renders them less desirable than warping. On the other hand, there are objections to weakening the structure of the main surfaces by making them movable.

There is a further distinction between these two methods of control, which, although not thoroughly understood in a general sense, appears to be borne out in practice, viz, when a plane is warped the action tends not only to tip the machine up on one side but also, due to the helical form thus assumed, to turn, which can be counteracted only by the vertical rudder. In the case of wing tips, however, due to the equal but contrary position in which they are placed, both sides of the machine are equally retarded and, in addition, since the main surfaces preserve the same shape and the same angle of incidence, this tendency to turn appears to be absent. Curtiss states that to correct for tipping alone, he makes no use of the vertical rudder.

Sliding panels, or "equalizers," as applied to the Pfitzner monoplane, represent one of the recently-designed methods of transverse control which are considered not to infringe the Wright patents. This system has not been adequately tried out as yet, but there appears to be no reason why it should not be as effective as either the system of warping or the use of wing tips. There are many other methods designed to give transverse control and it seems at present that they are all equally reliable. Structural individualities of the types of aeroplanes will persist, in all likelihood, so that we can not picture the machine of the future with any one form of transverse controlling apparatus. Balancing planes and wing tips, or ailerons, are widely used at present, but further progress in aerodynamics is likely to show that warping is better, particularly as the development of improved forms of construction and more suitable materials eliminate the objection of weakening the main structure as now built.

Aspect Ratio. It is at once observable from the values given that the ratio of spread to depth (aspect ratio) of the monoplanes is generally less than that of the biplanes. This interesting fact is due very likely to the structural difficulty of making the wing of a monoplane long and narrow, and at the same time providing the necessary strength without involving undue weight. The Antoinette monoplane has recently shown a departure from this standard by decreasing the depth and increasing the spread, thus increasing the aspect ratio, but the framework had to be greatly strengthened. The new model Voisin has the highest aspect ratio of the types considered here, but exhibits no remarkable qualities therefrom.

Both theoretically and experimentally the value of this quality is considered to have much to do with the ratio of lift to drift; but whether or not in actual practice those machines like the Santos-Dumont, having as low an aspect ratio as 3 to 1, are really inferior in their qualities of dynamic support to a machine like the Cody with as high an aspect ratio as 7 to 1, is difficult to determine, since so many other factors, such as the loading and velocity, are involved. It is interesting to note here that some of the large soaring birds, such as the albatross, may be considered as aeroplanes of very high aspect ratio. The effect of aspect ratio upon speed is not discernible upon comparing the types.

Greater stability, however, is commonly supposed to result from a high aspect ratio, because of the decreased proportionate movement of the center of pressure. A further advantage is that the higher the aspect ratio of a plane, the lower is the angle giving the maximum ratio of lift to drift, and consequently for given speed and loading less power is necessary. There appears to be little question but that the development of aeroplane construction of the near future will tend toward an increase in the aspect ratio to as high, possibly, as 12 to 1.

Incident Angle. The angle that the main supporting surfaces of an aeroplane make with the horizontal line of flight is termed the incident angle, and it is something that at present varies greatly in the different types. The Wright biplane is notable for its very low angle of incidence in flight, rarely exceeding two degrees.

Renard, after deductions from the experiments of Borda, Langley, and other investigators, has enunciated the principle that, *as the incident angle diminishes, the driving power expended in sustaining a given plane in the air also diminishes.* Wilbur Wright states that, *the angle of incidence is fixed by the area, weight, and speed alone. It varies directly as the weight, and inversely as the area and speed, although* *not in exact ratio.* Faraud concludes that small angles are the most efficient for all aeroplanes. There is for each type a most efficient angle of incidence, or point where the power expended for flight is least. In flying, the incidence should be kept constant at this angle in order to obtain the highest speed.

The Farman, Voisin, Bleriot XI, Grade, and Sommer have an angle of incidence when first starting much greater than when in flight. Since this involves greater drift resistance and consequently more power necessary to attain the velocity of levitation and, furthermore, as aeroplanes with as heavy a loading but without an excessive angle are able to rise after a reasonably short run, it would appear as if this provision were unnecessary.

Recent experiments in aerodynamics indicate that the ratio of lift to drift, with a surface of the shape now so generally used, varies little between the values of 2 degrees and 6 degrees, a maximum value being reached in the neighborhood of 3 degrees. This explains in a measure the wide variations in this angle as observed and recorded for the different types, and also that many of the present machines preserve their equilibrium during comparatively large changes of their longitudinal inclination.

In general, the incident angle of the monoplanes is greater than that of the biplanes. The most common angle is in the neighborhood of 5 to 7 degrees. But in the Bleriot XII, an incident angle of 12 to 13 degrees is often used in flight. Incidence will very likely be established purely by the lift-drift ratio of a plane, and the angle kept as constant as possible to give this its highest value.

Propellers. With one or two exceptions, aeroplanes of all types are driven by a single, high-speed screw. The Wright and the Cody are the only instances of machines provided with two propellers rotating in opposite directions. The greater efficiency of a propeller of large diameter revolving at a slow speed over one of small diameter and high rotative speed has attracted much attention. This seems to be borne out especially in the case of the Wright machine, in which more thrust is obtained per unit of power than in any other type. The limit of rotative speed in practice is approximately 1,500 r. p. m., and in all types excepting the Wright, Cody, and Bleriot XII, the r. p. m. rate exceeds 1,000. Many of the aeroplanes, more particularly those of foreign design, use the Chauviere wood propellers, for which an efficiency of 80 per cent is claimed. The Antoinette, Grade, and Voisin, use metal screws.

The thrust and efficiency of the various propellers are about the same for equal sizes, and although the theory of propeller design is very little understood as yet, the experimental methods used have resulted in the design of propellers of as good efficiency or higher efficiency than those used in marine practice. The position of the propeller in front in most of the monoplanes is largely a matter of convenience of design, although it has an advantage in that the swiftly moving mass of air thrown backward by the screw also exerts an added lift when thrown back on the plane. At the same time, however, this action also increases the resistance, but as the frame resistance of the monoplane is much less than that of the biplane, the propeller may be placed in front without any very serious consequences. The Voisin (tractor type) biplane has the screw in front, but the results obtained indicate that this is detrimental to the speed.

It is generally believed by aviators that much better results could be obtained by the use of propellers 15 to 20 feet in diameter, rotating slowly. But there are two disadvantages involved in this feature of construction which make its adoption in the machines of the future rather doubtful. The first is the greatly added weight of so large a propeller and the second is that of building a good chassis high enough to permit of the propeller rotating freely.

Rudders. The direction rudder in all types, except the Pfitzner, is placed at the rear. The Cody biplane has an additional direction rudder in front. All the monoplanes, with the exception of the Pfitzner, have their elevating rudders at the rear, while in all the biplanes, except the new Wright and more recent Voisin models, this rudder is placed out in front. Rudders placed at the rear are advantageous in that they act at the same time as keels. But, in general, the placing of the elevating rudder in front seems to offer more exact control of the longitudinal stability.

The elevating rudder almost always exerts some supporting power. Therefore, when placed in front and turned up for ascent, the support is increased, as it naturally should be. But when this rudder is placed at the rear, the movement for ascent is such that the supporting power of the rudder is decreased, making it of negative value, so that instead of causing the front of the machine to rise, it causes the rear to sink. Following the same theory shows that when the elevating rudder is out in front, in starting, the front of the machine lifts off the ground and is strongly followed by the body; while if this rudder be in the rear, when turned to give ascent the rear merely sinks more, and not only is the run greatly increased, but the power required and the risks incurred are greater. That it is generally so used on the monoplanes is the result of necessity due to the propeller being at the front.

In the Wright biplane the elevating rudder is so constructed that when elevated it is automatically warped concavely on the under side, and when depressed, curved in the opposite way. This materially adds to the rudder's force due to the peculiar law of aerodynamics whereby a curved surface, under the same conditions as a flat surface, has a greater ratio of lift to drift. The reduction in the size of the rudder is thus made possible and its flat shape when normal greatly reduces the head resistance. In so far as a biplane is usually supposed to cause interference of the two surfaces and greater head resistance, it would appear as if the biplane rudders as used on the Wright and the Curtiss were not as efficient as single planes, but the structural advantages of this arrangement are important.

The method employed by Grade of merely bending flexible surfaces, instead of turning rigid movable planes, has a great advantage in that the rudders, after being used, spring back to their normal position. This method has not been adopted on any other type, however, although it has many considerations of safety favoring it.

In almost all of the successful aeroplanes, with the possible exception of the Wright and Antoinette, it is conceded that the size of the rudders is much too great. This is clearly indicated by the remarkably small change of inclination usually necessary for a change of direction. This ultra sensitiveness where, as in some machines, a movement of a few hundredths of an inch will considerably alter the state of equilibrium of the machine, is certainly undesirable. To begin with, it need hardly be pointed out that oversensitiveness of a rudder usually invites dangerous situations. Furthermore, if a rudder be extremely sensitive, it is a good indication that it is too large, in which case it is absorbing considerable power that could be put to better use elsewhere. It is quite likely, therefore, that a great decrease in the size of the rudders will be a development of the near future.

Keels. Keels on aeroplanes, like keels on a boat, add greatly to the stability. But on an aeroplane they are "dead surfaces" and, as such, have the disadvantage of offering greater expanse of surface for wind disturbance to act upon. They unquestionably decrease the speed. Tapering keels, such as those employed on the Antoinette, the Pelterie, and the latest Bleriot XI, offer a maximum of "entering edge" with a minimum of area, and for that reason are more advantageous than those of rectangular form. Keels are entirely lacking in the original Wright, Santos-Dumont, and Cody, but in the later "headless" Wright two small, vertical keels of semicircular form are placed in the angles made by the meeting of the skids with the braces from the latter to the upper main plane, while a horizontal keel of considerable area is employed in the rear of the Short Wright (English manufacture).

In the Voisin, use is made of several vertical keels of large area, really partitions, placed not only in the rear cell but also between the main planes themselves. That these have not proved entirely satisfactory is indicated by the adoption of ailerons to maintain transverse stability in the more recent Voisin machines. Keels add greatly to the resistance of a machine, the head resistance and skin friction with their consequent power absorption being considerable. It is generally conceded now that control by rudders is becoming so perfected that any inherent stability to be obtained by the use of keels at the expense of power is hardly worth while. No special form or combination of keels, so far designed and tried, have really succeeded in giving any kind of complete inherent stability.

Actual practice, however, demonstrates that they do increase stability, tending to hold the machine to its course, and keels at the rear of a machine somewhat on the order of a bird's tail are found advantageous, so that it is quite unlikely that they will disappear as a feature of aeroplane design for years to come.

Mounting. This is the only remaining detail of construction that need be considered in this connection. There is probably no other single feature in which the various machines differ more widely, nor any other in which such totally different provision, or the absence of it, for absorbing the shocks of landing, proves so uniformly successful. When an aeroplane drops as a dead weight for even a short distance, it suffers considerable damage regardless of the presence of shock absorbers or otherwise, whereas, in ordinary use, it appears to be as easy to land lightly with a machine having a rigid chassis, as with one in which elaborate precaution is taken to guard against shocks.

There is another factor to be guarded against, however, and that is the gyroscopic action developed by the swiftly revolving propeller, which tends to resist a sudden change of its plane of rotation, as well as all vibration. If, therefore, when running over the ground the machine be suddenly jarred, the propeller is likely to snap off. This has been experienced by M. Bleriot on more than one occasion, and he emphasizes the necessity of providing springs on a heavy machine mounted on wheels.

Three distinctive methods of mounting have been employed to date:

(1) Using skids only, as in the original Wright machine. This is already obsolete, as it involved the use of special starting apparatus.
(2) Wheels only, as in the Curtiss, Voisin (both types), Bleriot (both types), Pelterie, Grade, and Pfitzner.
(3) Wheels and skids combined — Farman, Antoinette, Santos-Dumont, Cody, Sommer, and later Wright machines.

Details of some of the most important designs are given in Fig. 40.

The relative merits of mounting on wheels only or skids and wheels constitute a subject of wide discussion. Where the former are employed independently, the addition of a brake is almost indispensable to bring the machine to a quick stop where the landing area is restricted; whereas, with a skid forming part of the support, as in the Antoinette, the latter acts as a brake. Of course, it performs the same office in starting, to the detriment of a quick rise from the ground. The extra power required on that account, however, is not very great, as the skid, supporting only the tail, does not carry any great weight. It is consequently not very efficient as a brake either, so that provision of the latter class on all types should be made.

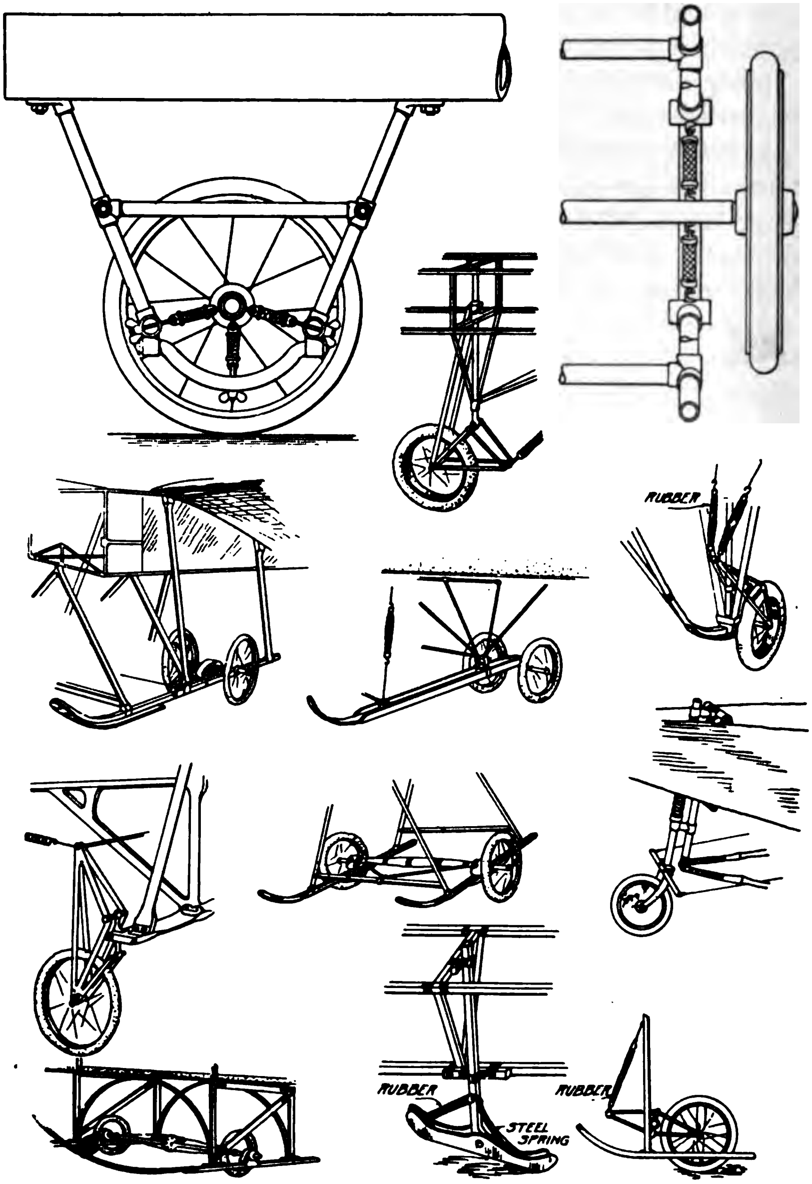


Fig. 40. Types of Landing Skids for Aeroplanes

A number of combinations of skids and wheels have been tried, such as that of the new Wright which starts on its four wheels, and lands on the skids to which they are attached. The Sommer and Farman are typical examples of this combined form of mounting, and experience in their use appears to demonstrate that they are the most effective for heavy machines. On light aeroplanes, such as the Curtiss and the Grade, where the loading is reasonably light, spring mountings have been found unnecessary, the wheels alone taking the shock of landing. No skids are employed. The more recent Curtiss machines are provided with an efficient brake. It is quite likely, however, that the high speed aeroplane of the future will not only be provided with an elastic mounting, but when regular stations are established, means will be employed for projecting it from some ingenious starting device at high velocity, so that it may be quickly launched into the air.

Speed. It is generally conceded that the chief object of the aeroplane designer at present is to increase the speed, prophecies of 100 miles per hour, and considerably more, being not at all uncommon. Whether this can be attained or not is a question that only the future can solve, but a comparison of the speeds prevailing in January, 1910, and December, 1910, shows such a marked increase for the development of a single year that this does not appear to be beyond the possibilities of the future, by any means. It must be borne in mind, of course, that while resistance increases as the square of the speed, the power to overcome it must increase as the cube. This would seem to make the attainment of the 100-mile mark something that would involve considerable modification of the present type of aeroplane, in order to attain increased efficiency, as the goal in view is not to be won by a mere increase of power.

The speed shows no direct variation with aspect ratio or loading, and higher speeds seem to be merely attained by an excess of power, a decrease of head resistance, and a small supporting surface. In Table I are given the speeds of the various types described, *i. e.*, those of which they had been shown capable up to January, 1910.

Flight. In the manner of flight of the different types, pronounced distinctions may be drawn. Probably the widest variation in this respect exists between the Wright and the earlier Voisin

TABLE I

Speed Data

Type	Miles per hour	Type	Miles per hour
Bleriot XI (Racing Type)	63	Farman (Racing Type)	44
Santos-Dumont	55	Sommer (1910 Model)	44
Bleriot XI Bis(1910 Model)	51	Wright (Rear Control)	43
Antoinette (1910 Model)	50	Wright(1910 Model)	41
Voisin (Racing Type)	49	Farman (1910 Model)	41
Curtiss	48	Voisin (1910 Model)	40
Bleriot XII (1910 Model)	48	Farman (Passenger Type)	39
Bleriot XI 2 Bis	48	Pelteric	39
Pfitzner	45	Cody	37
Grade	44		

with numerous vertical keels. The flight of the latter may be best described as "sluggish." The enormous resistance of this machine appears to hold it back very perceptibly, while in making turns its action is slow and "deadened." In sharp contrast to this is the strikingly active flight of the Wright machine. Its resistance is very small for a biplane and its movement through the air is quick and precise, particularly when compared with the flight of the Farman biplane, the sluggish movements of which at the International Meet near New York earned for it the sobriquet of "the ice-wagon." In changing direction or warping to maintain lateral stability, the action of the Wright is precise and almost instantaneous, the Wright biplane answering its helm in a remarkably quick and effective manner.

In grace of form and swiftness of flight the Antoinette and Bleriot monoplanes are a delight to the eye. They appear to move through the air without the slightest effort and at the distance of a mile or so give the impression of being huge, soaring birds, so steady and perfectly under control is their every movement. Due to the smooth whirring of their multi-cylindered motors, this is accentuated when close at hand, in comparison with the clattering exhaust of the four-cylinder Wright engine, which many uninitiated spectators mistake for a noise made by the propellers, the turning of which is plainly visible owing to their low speed.

The Curtiss in flight is noticeable for its constant rising and

TABLE II
Characteristics of Different Types

Machine	Pounds per h. p.	Pounds per sq. ft.	Speed in Still Air, m. p. h.
Wright	41	2.05	41
Wright (r. c.)	37	2.50	43
Farman (pssgr)	34	3.15	39
Bleriot XI	29	4.50	51
Antoinette	27	3.33	50
Pelterie	27	4.40	39
Cody	25	2.57	37
Farman ('10)	24	2.80	41
Pfitzner	24	3.20	45
Curtiss (pssgr)	22.6	3.64	. .
Voisin ('10)	22.5	3.14	40
Curtiss	22	2.50	48
Farman (rcg)	21	3.00	44
Bleriot XII	21	5.30	48
Bleriot XI 2	19.8	3.68	48
Voisin (rcg)	19.5	3.27	49
Voisin (tractor)	19	2.36	40
Grade	17	2.00	44
Sommer	16	2.76	44
Sommer (rcg)	15	3.25	. .
Santos-Dumont	12	3.10	55
Bleriot XI (rcg)	7.5	5.76	63

falling, tracing a sinuous, vertical path through the air, in contrast with the perfectly even and level keel maintained by most of the other machines. In making any comparison of flight, however, the personal equation also must be considered, as the action of the machine is largely governed by the skill of the aviator. In the present instance, however, the impressions recorded were of the different machines in the hands of skillful pilots, all of whom had been flying for a year or more and had made a great many flights. The Santos-Dumont was early dubbed the "clown" of the International Meet and its appearance was invariably the signal for a roar of amused applause. Despite its speed, its erratic action marked by continual dips and violent rocking, always seemed to have it on the verge of tumbling to the ground. Because of its light loading, the Grade seems especially buoyant in the air. The other types mentioned show characteristics between the extreme sluggishness of the Voisin and Farman and the remarkable preciseness of the Wright.

As the question of duration of flight depends much more upon the skill of the aviator, the endurance of the motor, and the amount of fuel carried than it does on the machine itself, a comparison of the longest flights made by each type would be valueless.

Efficiency. One of the best indications of the general efficiency of an aeroplane is the amount of weight carried per horse-power, but it will be apparent that this must also be considered in connection with the weight lifted per square foot of lifting surface, its speed, and similar factors. The first of these mentioned is usually termed "pounds per horse-power" and is obtained by dividing the total weight of the machine in flight by the horse-power of the motor. This is a variable owing to the different weights of the aviators, but not one of sufficient importance to record in the case of a one-man machine. At the time Table II was compiled (January, 1910), the Bleriot XI (racing model) appeared to be the most wasteful of power, while the Wright was the most efficient, this still being true of the latter. It must also be borne in mind that the Bleriot is a very much faster machine than the Wright. Table II summarizes the various characteristics of the different types.

HARRY ATWOOD IN HIS BURGESS HYDROAEROPLANE SKIMMING OVER THE SURFACE OF MARBLEHEAD BAY

TYPES OF AEROPLANES

PART II

SPECIAL TYPES

As explained under the head of "Standard Types," this designation is not intended to cover aeroplanes that can properly be regarded as standardized in the usual acceptance of that term, although with one or two exceptions they are built along essentially the same lines in their respective classes. In addition to the machines described in that category, there are hundreds of others which do not differ sufficiently from these types to merit reference. Besides these, however, there are some aeroplanes which are distinguished by radical departures from the accepted standards in question, or which have been designed for some special form of service, and no work on the the subject would be complete without at least a brief description of their distinctive features. All of these machines are of more recent construction and, as they are being brought out in rapid succession as the art develops, those given here naturally include only a limited number.

Paulhan Trussed Type. The most radical departure noted up to the present writing is a machine constructed for Paulhan, Fig. 41, in which by reason of utilizing tetrahedral surfaces similar to those of the well-known kites invented by Alexander Graham Bell, neither warping nor ailerons are required to maintain lateral stability. The planes of the Paulhan machine are built upon a form of trussed girder made up of two long, thin ash planks about 8 inches wide near their central section, and about $\frac{1}{4}$ inch thick, the general plan upon which the biplane is constructed being similar to the Curtiss machine. There is a central section containing the motor and the aviator's seat, the outer sections being attached to this central section in a novel manner. The planks in question are spaced about 8 inches apart and the lower one curves upward toward its ends until it meets the upper one. These two planks are tied together by a series of flat, steel plates forming a series of V's, thus forming a very rigid trussed girder that eliminates the necessity of using the numerous guy wires ordinarily employed. The ribs are attached to the lower members of these main girders by means of clamps passing over an armored wood fillet that lies within the base of every other V. The ribs are cut out of solid wood and are arched to the proper curve. The cloth is provided with pockets which enable it to be slipped on the ribs and laced in place. As the ribs are attached to the girders at their front ends only, they have a certain amount of spring or flexibility which, it is claimed, gives the machine a high degree of inherent stability.

Both the lower and upper girders are divided into sections and connected by uprights. The uprights of adjoining sections are placed side by side and fastened together by S-shaped leather straps which wrap around them and are drawn taut by a special fastener. Leather straps are also used to connect the uprights of the center cell to the chassis as well as in most other parts of the machine where joints must be made. Except for its tendency to stretch, leather affords a very strong and tough material for this purpose, while its use avoids the necessity of piercing holes in the struts. It is ideal for a machine like the Paulhan biplane here described and the Fabre monoplane, along the lines of which the former is constructed, as both are intended to be demountable in order to make them readily portable.

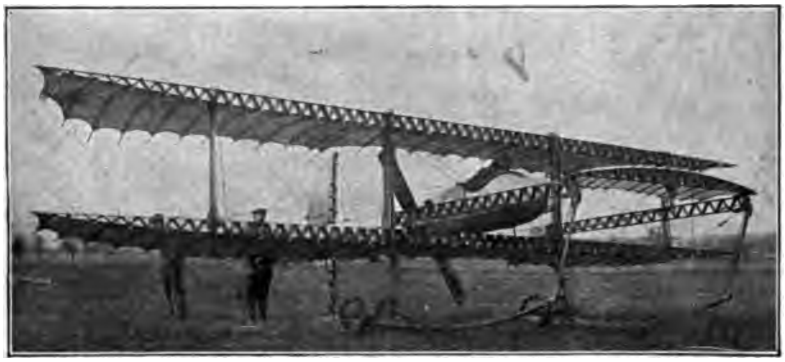


Fig. 41. Paulhan-Fabre Biplane with Tetrahedral Cell Girder Framing

There are two long, trussed girders running from the front of the lower plane out to the rear, where they support the single-surface tail and the vertical rudder in front of it, while at the front they carry the monoplane horizontal rudder, or elevator. The motor is on a frame back of the pilot's seat which is located in a torpedo-shaped aluminum car secured to the lower plane simply by crossed guy wires that run through it at the front. The car and frame are one and besides the 50-horse-power Gnome motor they carry a large tank for gasoline just behind the aviator and passenger's seats which are in tandem. The aluminum car is employed to protect the aviator and to reduce head resistance, the fore-and-aft girders having their sides covered with cloth for the same purpose. The machine is mounted on two skids placed beneath these two fore-and-aft girders, each skid being carried on a pair of pneumatic-tired wheels connected by a short axle which is attached to the skid by a rubber band and is guyed fore and aft to keep it from twisting.

In place of the single-control lever to which he has become accustomed in piloting the Farman machine, Paulhan uses a vertical steering wheel similar to that originated by Curtiss. Pushing or pulling on this wheel turns the horizontal rudder downward or upward, while turning the wheel operates the vertical rudder at the rear. No method of warping the wings or other device for correcting side tipping was shown on this machine when it was exhibited at the 1910 Paris show, and it is claimed that the flexible ribs in connection with the zigzag-girder construction give the machine sufficient transverse stability to make any provision of this nature unnecessary. The machine has been flown successfully and proved remarkably steady in flight, from which it is evident that the means at present in use of maintaining lateral stability mark only the first steps toward what may be eventually accomplished in this direction.

In addition to this important feature, the chief claim made for the machine is the rapidity with which it may be assembled or demounted. The end cells may be detached by taking out three bolts at the top and bottom of the uprights, an operation that requires only a minute or two at the outside, while the whole machine may be taken apart and packed in a case 15½ feet long by 3¼ feet square, within an hour. The ready detachability of the end cells makes it possible to store the machine in an ordinary shed, as the total spread of 38 feet is reduced to 12 or 15 feet when these sections have been removed. The fore-and-aft length of this new biplane is 25½ feet and, including the horizontal rudder and the tail, the area is 300 square feet. The total weight of the machine itself is 800 pounds, which is low, considering its size and heavy construction.

M. Fabre, designer of the hydroaeroplane described later, is also responsible for the construction of this Paulhan biplane, and makes the following claims for his system: Great strength and rigidity; small head resistance; absence of trussing wires with their liability to loosen or break and their considerable head resistance; automatic transverse stability due to the zigzag girders resembling tetrahedral cells—the most stable form of supporting surface; and its ready portability.

In view of the supporting power and stabilizing effect of the trussed girders, it is interesting to note that, assuming the machine's critical speed to be 45 miles an hour with the cloth planes in place, the girders would support its 800 pounds of weight alone were the speed increased to 120 miles an hour. If it were possible to reef the cloth of the wings while in flight, it would, therefore, be possible to keep diminishing the supporting surface until this consisted of the girders alone, while the speed would increase to 120 miles an hour, or more.

Three years ago, Santos-Dumont constructed a small biplane having its supporting surfaces set at a sharp dihedral angle. Wood was used for the aeroplane surfaces, and it was thought the machine would be very speedy. However, the supporting surface was so small in proportion to the weight that it was difficult to attain sufficient speed for a sustained flight, and almost at the first attempt the machine was smashed and abandoned. The Paulhan biplane with reefed surfaces would be an almost direct descendant of Santos-Dumont's wood-surfaced flyer, and the possibility of a machine flying under bare poles, so to speak, would give an idea of what might be accomplished in the future. The promise of the "reefing aeroplane," as it may be termed, is being seriously considered and will be treated later in this article.

Nieuport Monoplane. More than ordinary interest attaches to the Nieuport monoplane, as, while it does not differ radically in design from the majority of French monoplanes, it is not only the simplest but likewise the most efficient type thus far produced and it is to be greatly regretted that its creator, Edouard Nieuport, should have met an untimely death in an accident, as the great success of his efforts in the two years that he devoted himself to aviation presaged greater and more important developments. During 1911, the Nieuport monoplane earned for itself the title of the "fastest aeroplane." Weyman's 100-horse-power Nieuport made an average of 78 miles per hour in the Gordon-Bennett, winning the trophy for America, while a 30-horse-power machine of the same make made 58.9 miles per hour in the same event. What this means may best be realized from the fact that the original Wright biplane with a motor of the same rating could not do better than 40 miles per hour. A 70-horse-power Nieuport has made 74.8 miles per hour, as compared with the speed of 61 miles per hour made with the 100-horse-power Bleriot which won the 1910 Gordon-Bennett. In the French military competition, Weyman's 100-horse-power Nieuport averaged 72.6 miles per hour for 186 miles with three people.

The construction of the Nieuport type for two persons, fitted with a Gnome 50-horse-power revolving motor is as follows:

The wings are built up on two main spars of ash, while between these spars are run three light battens merely to tie the ribs together. The ribs, of which there are 13, are of I-section, built in the usual manner and with the webs perforated to save weight, while the box ribs are built up by using two webs and larger top and bottom flanges. The rib curve varies in each rib, decreasing toward the wing tips and going down to a flat bow. The wing section given in the sketch, Fig. 42, might be taken as the standard curve, allowance being made for the different chord at various places, and also for the different thicknesses of the spar, which tapers both ways from a straight central portion. It will be noted that there is a slight reverse curve on the under surface at the trailing edge, while it is very pronounced on the upper surface. Each wing is trussed with two heavy standard cables, top and bottom, to each spar, and they are set at a slight dihedral angle. The fuselage longitudinals are also of ash, rectangular in section, and channeled out between the struts to achieve lightness. Rectangular ash struts are also employed, except those for the skids, which are steel tubing. Connection between struts and longitudinal members is made by aluminum castings to which the wire bracing is anchored. The entire structure is covered with fabric.

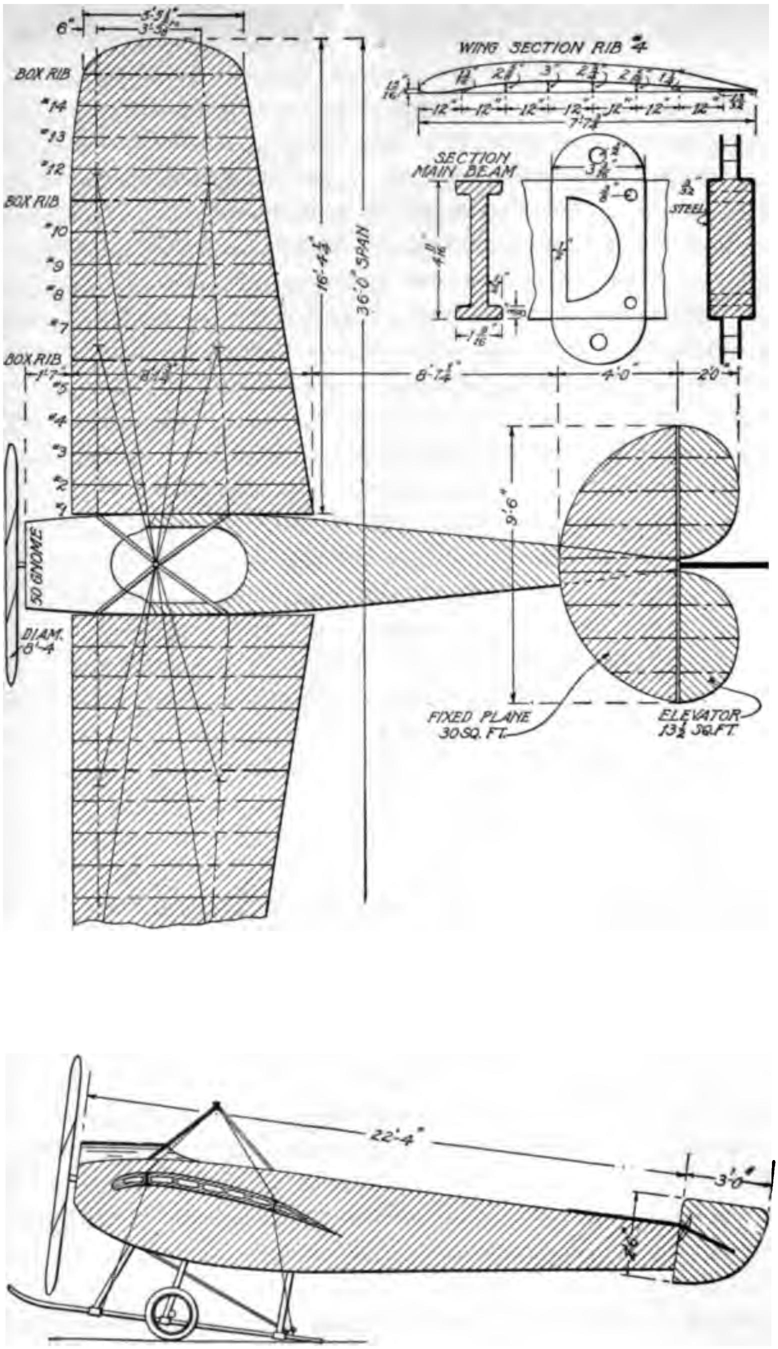


Fig. 42. Details of Nieuport Monoplane

Control is by means of a single hand lever, operating the rudder and elevating plane, while a bar for the feet works the warping mechanism. This single hand lever is mounted by a swivel joint on a short shaft lying along the floor inside the body. A forward and backward movement of this lever operates the elevator by wires passing around pulleys mounted at the ends of the rocking shaft, while a lateral movement of the lever actuates the rudder wires through a crank formed by an extension of the rear pulley sheave which is fixed to the rock shaft. The elevators are semicircular in plan, and are constructed of steel tubing frames covered with fabric on both sides, the tail or fixed plane also being built of steel tubing, while nothing but steel is employed in the construction of the running gear, the central skid, the axle which is made of a single, five-leaf spring, and the oval skid struts. The V-members are made up as a unit and can be slipped over the skid and put in place in a short time should repairs be necessary. The extreme simplicity of this running gear is apparent at a glance, Fig. 43. The power plant is a 50-horse-power Gnome motor, driving a two-bladed propeller 8 feet 4 inches in diameter. The span is 36 feet, the wings having an extreme width of 8 feet 1¾ inches, where they are joined to the fuselage, and tapering to 5 feet 5½ inches at their outer ends, the total area of the main planes being 221 square feet, while the tail or fixed rear plane of semicircular form, placed 8 feet 7¼ inches back of the wings, has an area of 30 feet, and the elevators, which are practically part of the tail, being hinged to it, have a spread of 13½ square feet. This makes a total area of 274½ square feet, which on a

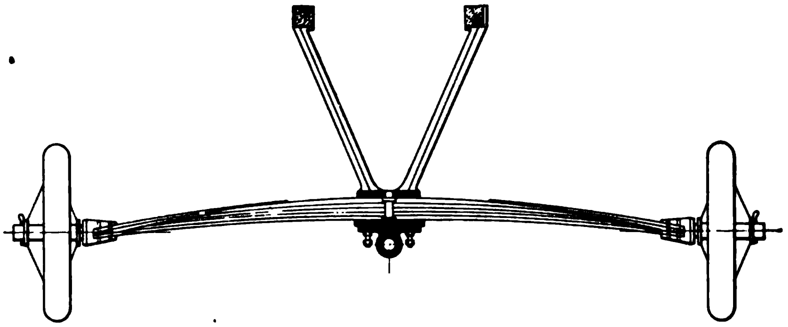


Fig. 43. Nieuport Running Gear

total weight of 715 pounds, exclusive of the aviator, gives a loading of 2½ pounds, or of 3⅓ pounds with the pilot, assuming the latter's weight to be 170 pounds, as is customary. The overall length, exclusive of the propeller shaft, is 25 feet 4 inches.

Bleriot Limousine. The Bleriot Limousine, Fig. 44, is a novel aeroplane that marks an advance in development, as it is the first to appear with a closed body for the passengers. The aviator sits forward and outside of the body, the resemblance to a cab thus caused having also earned for it the name of the "aerial taxi." This machine was built by Bleriot to the order of M. Henri Deutsch, who has probably done more for aviation in France than any other single individual. In general design, this machine somewhat resembles the original Bleriot XII and, like the first passenger-carrying machines turned out by this maker, the passengers are seated in the center below the main plane. In all other respects, however, it is different, and appears to constitute more or less of a reversion to the original Wright type, the horizontal being placed some distance out in front, while a stabilizing plane and the direction rudder mounted over it, are carried some distance behind the main planes. The power plant is a 100-horse-power, fourteen-cylinder Gnome revolving motor, and it is mounted at the rear of the main plane, instead of at the front, the fuel being carried in a torpedo-shaped tank above the roof of the cab and just in front of the motor. Control is by the usual Bleriot method, consisting of a universally-mounted post having an aluminum bell at the bottom to which the control cables are

Fig. 44. Bleriot Limousine or Aerial Taxicab

fastened. Complete, but without any passengers or the aviator, the machine weighs 1,540 pounds, and it has a supporting surface of $430\frac{1}{2}$ square feet, triple heavy rubber bands being employed as shock absorbers on the chassis, to sustain the unusual weight. The spread of the main plane is 43 feet, and the overall length of the machine is 46 feet. Although it would seem that the twenty odd square feet of surface presented head to the wind by the front wall of the body would cause a seriously detrimental head resistance, the machine has flown very successfully, showing itself to be capable of carrying two passengers, besides the aviator, at a rate of 50 miles per hour. The seats in the body are fitted with pneumatic cushions to take up the shock in case the machine alights heavily. A speaking tube is provided, so that the passengers can communicate with the aviator. This is the first time that a machine has been built and flown in which special care was taken to construct it with a comfortable body for the carrying of passengers, and it is doubtless the forerunner of many more of a similar type that will make their appearance in the next few years.

Tatin-Paulhan Aerial Torpedo. M. Victor Tatin, who is responsible for the design of this extremely novel-looking aeroplane, has waited twenty years to see his ideals realized. He originally designed the machine about 1890, and has argued for the correctness of its lines in several brochures and books published in the interval, though the machine itself was not built until the latter part of 1911. The body is completely enclosed from end to end and reveals a fine example of the pisciform shape recommended by Renard for the dirigible. The propeller is placed at the extreme rear and the direction rudder is placed just above the elevator, a few feet forward of the propeller, so that without the wings the resemblance to a fish is striking, while the upturned outer ends of the main planes give it the appearance of a large soaring bird. This upcurving of the wings is said to provide stability to an extent that makes wing warping unnecessary, while the torpedo-shaped body cuts the head resistance down to a minimum. The machine is provided with a flat tail, the rear part of which is movable and forms the horizontal rudder. The pilot's seat is located in the body just forward of the wings, and the 50-horse-power Gnome motor is placed just back of the pilot in a special compartment. The chief peculiarity of the design is the placing of the propeller at the extreme rear, instead of forward as is usual in monoplanes. Drive is by means of a long, universally-jointed shaft running back from the motor and carried in five bearings supported by piano-wire guys. The chassis consists of two wood beams bent in semi-elliptic form and connected at the lower part by an axle fitted with shock absorbers and carrying two pneumatic-tired wheels.

Bleriot Racer. That increased speed is largely a matter of refinement of detail based upon experience is evident from the 1911 Bleriot racer, which has developed a speed of 81 miles per hour with 50 horse-power, its designer having taken advantage of the lessons taught by the several long-distance European aeroplane races, most of which were won by Bleriot machines. To reduce head resistance, the upper flat cross member of the usual Bleriot chassis has been placed below instead of on top of the body. This results in shortening the steel tube uprights. The body has been made extremely narrow at the front, while at the rear it flattens completely, terminating in an absolutely flat horizontal rudder. The extreme front end narrows down to not quite a foot in width, though ample space is allowed for the aviator, while a long aluminum hood covers the tanks and motor and prevents the usual spray of oil in the aviator's face. The usual running gear and shock absorbers are placed forward, while the bamboo skid is at the extreme rear end of the fuselage. Beside the usual simple V-shaped support for attaching the bracing wires of the wings, the bracing tubes below are employed and they have been made considerably longer besides being well guyed to the body. They carry the warping mechanism at their lower ends and this has been modified in some ways. The vertical rudder has the outline of a shark's fin and is carried on top of the tail, as in the Bleriot XII.

This is the twenty-seventh different model that Bleriot has constructed. It has a span of 23 feet, an overall length of 29 feet, and a supporting surface of only 129 square feet, while its weight complete is 948 pounds, which gives the unusually high loading of 7 pounds per square foot.

Bleriot Canard. In contrast with the Voisin canard, or duck, as an aeroplane with the aviator in front in a covered body and the motor behind has come to be known in France, this machine is a monoplane, Fig. 45, and instead of being new is a revival of one of Bleriot's earliest attempts. Santos-Dumont was really the inventor of this type of machine and with its aid he was the first man to leave the ground in a power-driven aeroplane in Europe. The new Bleriot canard is much shorter than the Voisin, its thick, short body projecting forward of the monoplane wings but a small distance, the horizontal rudder being placed at the tip end of the bow, while two tiny vertical rudders on top of the main plane at each end serve to steer. The wings are guyed to an inclined rod beneath, which extends forward from a shoe on the bottom of a vertical post. Generous-sized, hinged ailerons are employed instead of warping the wings. The running gear is the same as that of the Nieuport, while the span and area of the machine are identical with those of the Bleriot racer just described, the total overall length being but 18 feet, while the weight complete with a 50-horse-power Gnome motor is only 882 pounds. The aviator's seat is so far forward that it would seem as if he ran very little risk of being injured by the motor in case of a fall, since there are five or six feet of stout framing between the engine and the pilot. A peculiarity of this type of machine is that in flight it appears to be going backward.

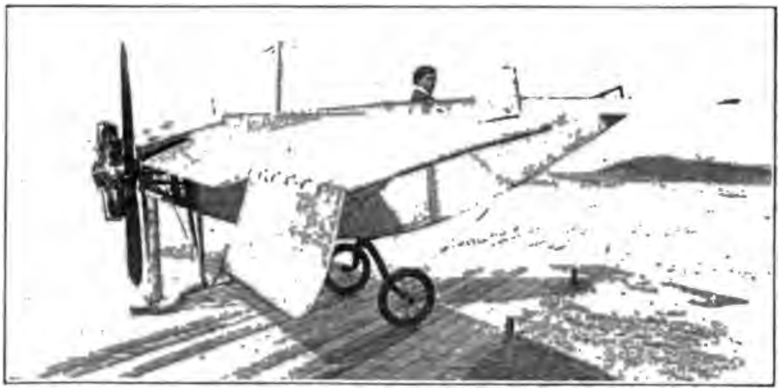


Fig. 45. Bleriot Canard Showing Unique Position of Engine and Propeller

Antoinette Armored Monoplane. Excess weight appears to have lost all its terrors for the designer of aeroplanes, as where every effort has been made previously to reduce this to the absolute working minimum, the builders of the Antoinette have brought out a machine in which the most vulnerable parts, such as the motor and chassis, are protected by armor plate. This machine was designed especially to take part in the French military competition, and by far its most important feature is the total elimination of all cross wires, struts, and the like. Every part is enclosed, even the wheels and the skids, with the result that the head resistance is greatly decreased, but the weight increased still further, at the same time giving the machine a most peculiar appearance. In addition, a peculiar wing section is used, flat on the under side and curved on the upper. Aerodynamical experiments have shown this type of wing section to have a very bad drift resistance at low angles of incidence and a very uniform rate of change of the ratio of lift to drift under the same conditions. The center of pressure does not move back as rapidly as on other shapes, as the angle of incidence decreases below 10 degrees. This type of wing is, therefore, more stable and of smaller resistance. The distribution of pressure, however, is very uneven, but because of the great strength of the planes themselves at all points, this is not a disadvantage. The wings are immensely thick, being braced entirely from the inside and measuring over two feet in section where they join the body—something altogether without precedent in aeroplane design. Their section decreases to 8 inches at the wing tips. The shape of each wing is trapezoidal and they are placed at an extreme dihedral angle. This adds to the stability of the machine in a calm, but in gusty winds conditions arise where a large dihedral angle is considered by many to be extremely dangerous. The boat-like body is completely enclosed and is very capacious. The motor of the regular eight-cylinder Antoinette V-type, of 100 horse-power, direct connected to a Normale two-bladed propeller, is placed at the extreme forward end, while the aviator's seat is in the body at a point between the wings. Though equipped with a 100-horse-power motor, the machine is said to be capable of flying with but 60 horse-power. The oddest feature of this type is the landing gear, which is entirely enclosed to within a few inches of the ground. There are six landing wheels forward, three on each side of the center and enclosed in what is termed a "skirt." Two smaller wheels are placed at the rear. The dimensions are: Spread 52½ feet, length overall 36 feet, width of wings at body 13 feet, at tips 9 feet, area of supporting surface 602 square feet, total weight, including aviator and fuel, 2,400 pounds. The aviator obtains a view below the machine through the glass floor of the body under his seat. To reduce resistance to a minimum, even the exhaust pipes of the motor are covered with a stream-line design shield. This type is of an immense size as compared with its predecessors and is very bird-like in flight, several successful trials having been made with it. But whether the great sacrifices made to eliminate projecting spars and wires are wise, remains to be seen. The machine has an unusually large expanse of vertical surface which makes it difficult to handle in a gusty wind.

Short Two-Motor Biplane. Although the Gould *Scientific American* prize of $15,000 for a successful two-motor aeroplane in which either motor can be used independently, and the second started in mid air in case of the accidental stoppage of the other, has now been open for almost two years, there have been few attempts to win it. A Queen monoplane was built during the summer of 1911 for this purpose and fitted with two 50-horse-power Gnome motors, but on the occasion of its first trial it came to grief. M. Legrand, the French engineer, has brought out a racing biplane equipped with two 100-horse-power, fourteen-cylinder Gnome motors, and this machine was flown successfully by Guillaume at Juvisy in October, 1911. The Coanda biplane, entered in the French military competition, was also provided with two motors driving the propellers through shafts and bevel gearing. The Short biplane, equipped with two motors, has made duration flights exceeding one hour, so that it is capable of fulfilling the conditions of the Gould prize, though not eligible for the latter as it is a foreign built machine.

In general outline it is a biplane of the Farman 1910 type, equipped with two 50-horse-power Gnome revolving motors, placed centrally and one in front of the other in the rear of the lower main plane at either end of a nacelle or enclosed body. The front motor drives two propellers in opposite directions by means of chains, precisely as on the Wright biplane. The propellers are of high pitch, similar to the Wright type, but are placed in front of the main cell, instead of behind it. The rear motor drives a single low-pitch propeller at high speed as on the Farman machines. It is possible to operate either motor separately or both together, and the feasibility of the arrangement has been well proved in actual flights. The rudder and aileron controls are of the usual Farman type, the landing chassis and all details of the construction having been made specially strong owing to the extra weight. The aviator sits in the enclosed body and there is a seat for a passenger beside him. With the immense extra power available, one motor sufficing for flight, this type has the ability to go fast or slow, and with its full 100 horsepower can climb very rapidly. The axes of the front propellers and the rear one are not on the same level, this being done to counterbalance the effect on the tail caused by the draft from the rear propeller. As soon as the latter ceases to operate the lifting tail sinks, but the higher position of the axis of thrust of the forward propellers at once overcomes this. The dimensions are: Spread 34 feet, chord 6½ feet, supporting area 435 square feet, weight in flight 2,000 pounds. The speeds are said to range from 35 to 50 miles an hour depending on whether one or both motors are operated.

Dunne Biplane. This is a machine of unusually novel type for which a great deal is claimed, but unlike the thousand and one machines that are built around claims and do not get much further, the Dunne has given evidence of its ability to do what its inventor claims for it. However, it is put forward as a machine in which automatic stability has been achieved, where, as a matter of fact, the design is one possessed of an unusually high degree of inherent stability, there being no devices or mechanism to give automatic stability in the sense that that term has come to be understood. Instead of having the main planes in a line with one another, they are in the form of a large **V** with its apex forward, so that while the machine is tailless in that there are no supplementary surfaces of the class termed tails or stabilizers, the ends of the **V** extend so far back that it actually has two tails instead of one, and upon this fact is based much of its ability to maintain equilibrium. The official report of a test of the Dunne witnessed by Orville Wright and Griffith Brewer in December, 1911, is in substance as follows:

> The first flight was over a distance of about three miles, the machine being turned at a height of about 100 feet and making a good landing near the starting point. During the second flight of 2 minutes 29 seconds, Mr. Dunne made notes on a piece of paper (involving use of both hands). In both cases, the engine was cut off in the air before landing and the machine came down without materially altering its angle of incidence.

A resumé of Dunne's patent will serve to show most clearly what his aims are and how he achieved them, reading "inherent" instead of "automatic" stability. The patent was granted early in 1910 in England and covers the "curvature and shape of surfaces."

> The object of the invention is to obtain a form of aeroplane which shall possess, solely by the form and arrangement of its surfaces, automatic stability in still and agitated air, and freedom from oscillation. The inventor has found that twisting the wings of an aeroplane involves the disadvantage that sections, either longitudinal or transverse, taken across the wing tip, give curves that are more or less concave on their upper sides, thus failing to give large pressure reactions, and that when such wings are twisted, the changes brought about in the pressures by the concave portions are so abrupt as to produce unsteadiness, and that the similar concavity on the transverse section produces lateral instability. The two essential conditions to be observed are to decrease gradually the angles of the fore-and-aft cross sections of the wings from root to tip, without producing points of inflection in the surfaces; and secondly, to maintain considerable differences in the angles of the inner and outer portions without too much loss of pressure under the outer portions. The present invention consists in constructing each of the main surfaces as a rearwardly projecting wing whose angle of incidence decreases from the root to the tip, and by shaping the wings so as to compress air between the positively-inclined portion of the wing near the root to the negatively-inclined portion near the tip. The wings must be so sloped backward along their leading edges that the wing tips lie behind the center of gravity of the whole aeroplane. Further, each wing is so constructed that its upper face is formed as a portion of a cone or a cylinder, the angle of incidence of the wings decreasing toward the tips, and in some cases changing sign, *i. e.*, negative to positive angle, or *vice versa.*

The principle is applicable to the monoplane quite as readily as the biplane, one of the former type of Dunne machines having been exhibited at the Olympia show in 1911. Like its prototype, it is designed to possess natural stability, and it is tailless in the ordinary sense of the term. In principle, however, the V-plan of its wings gives it two tails instead of one, and the hinged flaps on the trailing extremities of its wings give it two elevators instead of one. These flaps are under independent control, and serve the purpose of steering the machine horizontally and vertically. The special formation of the wings already referred to in the case of the biplane, is likewise generated on the surface of a cone, but the apex of the cone is an entirely different place, being situated, on the monoplane, a short distance behind the trailing extremity of the wing and more or less directly in line with the outside edge. This formation of the wing gives a variable angle of incidence from shoulder to tip, which, in conjunction with the V-plan form, confers on the machine the principles of the fore-and-aft dihedral angle, which is one of the accepted methods of obtaining natural stability and is a characteristic feature in the design of all successful aeroplanes. Owing to the wing extremities being situated in an exposed region and not sheltered behind the middle portion of the plane, as is more or less the case with the tail of an ordinary aeroplane, Dunne claims that their tail effect is enhanced. Also the same argument applies to the efficacy of the dihedral angle, because, owing to the formation and continuity of the wings, it is impossible to define what part constitutes main plane and what part tail. In fact the relative functions of these members are performed by different parts of the wings in accordance with the requirements of the moment.

Lateral stability in the Dunne monoplane is somewhat more difficult to explain, but the most significant feature of the design is unquestionably the fact that the wing formation provides down-turned wing tips, as distinct from the upturned wing tips on several other monoplanes, all of which are designed more or less with a view to natural stability. It will be noticed, of course, that it is the leading edge of the Dunne monoplane that is turned down, whereas in the Hadley, Page, and Weiss monoplanes, it is turned up, so that the relative positions of the leading and trailing edges in all three machines are identical. On the other hand, there is a very material and fundamental difference in principle between the two methods, for whereas the upturned trailing edge represents the lateral dihedral angle, the down-turned leading edge represents the gull's wing, which is an accepted method of obtaining lateral stability in side gusts. The general action is as follows:

A side gust ordinarily lifts that side of the machine against which it first strikes, because of the aeroplane action of the planes considered in their attitude toward the gust and the consequent travel of the center of pressure toward the leading edge facing the gust, which involves an actual travel of the center of pressure laterally from the real center of gravity of the machine. Thus the machine cants over and the upset is emphasized with the dihedral angle, because the upturned wing offers an increasing surface for normal pressure. In the gull's wing method, the remoter down-turned wing tip presents the more effective surface to the gust and tends to counteract the lift due to the travel of the center of pressure on the remainder of the plane. It is, in principle, little more or less than the idea which was tried by the Wright Brothers in some of their early gliding experiments. Like most things of this kind, however, there was all the difference between the broad principle, and the detail of carrying it into effect on a practical machine. It is the latter that makes the Dunne monoplane such an original monoplane.

De Marcay-Mooney Monoplane. In this machine there has been materialized, for the first time, a practical form of folding-wing construction. Taking advantage of the system of construction developed by Bleriot and other French designers in their monoplanes, each wing has been made integral together with its supports and bracing guys, the design otherwise being the same as the Bleriot except as necessarily modified to meet the purpose in view. Each wing is pivoted at its point of attachment to the body, to an outward-sloping metal upright that serves as a mast or strut from which the bracing wires are strung, in addition to its functions as a hinge. A wheel alongside the driver's seat controls the position of these wings, and by turning it the change is effected from the usual full spread for flying to the closed position over the body, in which form the machine bears a most striking resemblance to a huge beetle. In both positions, there is provision for securely locking the wings in place. No attempt has been made to permit of altering the position of the wings in flight, the novel design having for its sole purpose the more compact stowing of the wings while the machine is on the ground, to facilitate storage and to permit of its being driven along narrow roads or across other than clear fields. To facilitate the latter operation, the wheels of the landing chassis are movable and can be controlled by a steering gear provided for the purpose. This running gear suggests that of the Breguet, which is similarly steerable on the ground, and, in fact, apart from the folding wing feature, the machine is along conventional French lines. Lateral stability is obtained by warping the wings in the usual manner, while the tail is apparently a blending of the Nieuport and Bleriot fan-tailed designs. The fuselage is a characteristic four-car, tapered-box girder, covered with fabric and providing seating accommodation for the driver between the wings. Though there has been no attempt on the part of its makers to embody this improvement in the present machine, it has been pointed out by several authorities that folding the wings in this manner undoubtedly approximates the means employed by the birds for varying speed, and that when it is discovered how to apply these in a practical way, without longitudinal shifting of the center of gravity, the long-desired variable speed aeroplane will have become a reality.

Variable Speed Aeroplanes. As at present designed, every aeroplane has what is termed its critical speed, *i. e.*, the rate of its travel through the air at which it sustains and propels itself most efficiently. In many designs this is almost a fixed factor, *i. e.*, the aeroplane can not sustain itself in the air in case its speed falls to any extent below this critical point. Take the old type Wright biplane as an example. This had a speed of 40 miles per hour, but its stability became precarious at 35 miles per hour, or a drop of slightly over 10 per cent, while at 30 miles per hour, it probably could not keep to the air except by making dives and thus taking advantage of the acceleration of gravity. With the greatly-increased speeds that have been obtained with the aeroplane, a variable-speed type is more to be desired than ever, as a landing, to be safe, must be made at low speed. Probably one of the greatest variations in speed shown by an aeroplane thus far is that of Bleriot's 100-horse-power racer which won the Gordon-Bennett trophy at Belmont Park in 1910, at an average speed of practically 70 miles per hour, but which started and alighted at 50 miles per hour. It is not always possible to select safe landing places, particularly when compelled to alight, and the danger of landing increases with the velocity. A substantial prize has accordingly been offered by the Marquis de Dion, through *L'Auto* (Paris) for aeroplanes which can travel over a given course with the greatest variation in speed. To a degree, the Breguet monoplane meets these conditions, as it can vary its speed greatly by changing the angle of incidence of its sustaining surfaces. As yet, however, this has not been developed to a point where the change can be made during a flight, so that unless the Breguet is permitted to change its angle of incidence between trials, it will not possess any advantage over the machines with fixed wings. According to aeroplane constructors, the minimum speed on striking the ground with the motor stopped, is three fourths of the starting velocity. For the Bleriot this would be 37 miles per hour. The disastrous effects of striking a slight elevation of ground at such a speed and with a vertical velocity of 10 or 12 feet per second, may easily be imagined, and the danger increases with the size of the machine. The further development of the aeroplane depends largely upon the successful provision of a factor of safety in this respect. There is, of course, a great temptation to employ a water surface for landing, if possible, as this is not only level but it forms an admirable buffer against shocks. Moreover, a large aeroplane can be mounted more conveniently on rigidly connected floats than on wheels and springs. But with this construction it would be also necessary to rise from the water, starting at the low speed at which the propeller could drive the craft when afloat.

In order to combine high maximum speed with low speed in starting and landing, and for emergencies, the inclination of the sustaining surfaces must be capable of variation, so that the speed can be varied greatly while the axis of the machine remains horizontal, and the propeller must be designed to work with maximum power and efficiency, using the full power of the motor at all speeds of the aeroplane, for in starting, especially from the water, full power must be employed. An aeroplane propeller driven by a constant speed motor exerts a maximum thrust when its blades have a definite inclination, which varies with the speed of the aeroplane. For the purpose of automatically adjusting the propeller blades to the angle of maximum thrust at every speed, flexible blades are employed by Breguet, a centrifugal governor by Capon, and an electric regulator by Reister-Picard. The devices of Breguet and Capon are simple, but only approximately solve the problem; while that of Reister-Picard is perfect in theory, but complicated and delicate in practice.

Breguet. Breguet's original flexible blade was formed of rubber cloth stretched over a series of flat steel springs, which were attached at one end to the rigid front edge of the blade, but the construction was afterward simplified by adopting a rigid blade, capable of motion around its edge, and controlled by a single spring. Breguet has carried six persons in an aeroplane fitted with a propeller of this type, driven by a 50-horse-power motor, and has since developed a three-bladed, flexible type which promises even better results. In this, each blade is attached to the shaft by an arm, and is free to oscillate, under the control of springs, about three axes. At starting the blade turns on its axis so as to strike the air at a very small angle and produce a maximum thrust. As the aeroplane gains speed the blade returns toward its normal position, and thereafter automatically adapts its inclination approximately to the speed of the aeroplane. The blade protects itself against the irregularities of the motor by turning slightly in its plane of rotation about its point of attachment to the arm, and also by rocking backward and forward.

Capon. Capon's system of regulating the inclination of the propeller blades by means of a centrifugal governor is very simple in theory and construction; but the inclination of the blades is controlled entirely by the speed of the motor, and is not affected by the speed of the aeroplane, unless the former is made to depend upon the latter by another regulator. This is not the usual practice, nor is it desirable, as the efficiency of the internal combustion motor is impaired by alterations of its normal speed.

Reister-Picard. In Reister-Picard's system, each of the two blades of the propeller is attached to an arm which can be turned on its axis by a crank connected through a linkage to a spring-controlled sliding collar on the propeller shaft. This collar is in turn connected to a hand lever by means of which the pilot can alter the angle of inclination of the propeller blades to give the maximum thrust, as determined by the reading of a pressure gauge in front of him. This gauge communicates with a small annular vessel filled with lubricating oil and fitted with a piston so as to put pressure on the oil. This vessel is directly back of a bearing next to the collar, so that it gives a visible indication of what the propeller is doing at any moment. The same result can also be obtained automatically by means of an electric solenoid and plunger, the circuit of which is made and broken by a spring piston in a small oil cylinder communicating with the main oil chamber already referred to. In action, the coil of the solenoid would be intermittently energized by currents traversing it first in one direction and then the other, which would tend to maintain the thrust at its maximum value, but, like automatic stability devices of a similar nature, the apparatus is too delicate to form a practical adjunct to the aeroplane in its present state of development. Reister-Picard has also designed an aeroplane in which the inclination of the sustaining surfaces can be varied. This is practically a double biplane, Fig. 46, having a biplane elevator *E* forward and a vertical rudder *G* at the stern. The two biplanes are connected by a braced girder *P*, which serves to support the power plant and its accessories. The four slightly arched sustaining surfaces *X* are capable of rotation on transverse horizontal axes *Y*. *M* is the motor, *R* the fuel tank, and *C* the mechanic's seat, *L* being the lever by which he can control the inclination of the propeller blades if their automatic regulation becomes deranged. *S* is the seat of the pilot who operates the rudders and also varies the inclination of the sustaining surfaces by turning the wheel *T*. The mean inclination of these surfaces to the horizon, as they are drawn in the figure, is about 15 degrees, but their inclination can be diminished to 5 degrees as indicated by the dotted line *w*, for soaring at very high speed, and increased to 30 degrees, as indicated by *K*, for landing. In starting from rest on the ground or water, the surfaces are set as nearly level as possible. When sufficient velocity has been attained, the angle is suddenly shifted to 15 degrees, and the aeroplane rises without calling upon the full power of its motor, as is the usual practice. The inclination of the sustaining surfaces is then gradually diminished and the power increased by operating the throttle until the maximum power is being developed. At this time, the inclination of the sustaining surfaces is about 7 degrees and the aeroplane has attained its normal speed. In landing, the inclination is gradually increased to 15 degrees, while the power is diminished, the motor being stopped just before the ground is struck and the inclination is then suddenly increased to the full 30 degrees, enormously increasing the head resistance and bringing the aeroplane to a stop in a very short distance.

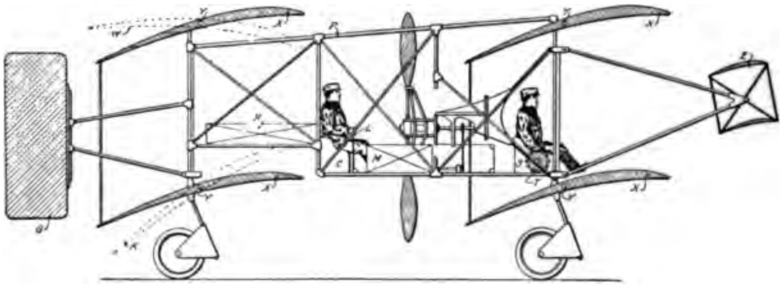


Fig. 46. Reister-Picard Double Biplane with Provision for Inclining the Supporting Planes

Etrich Bird-Wing Monoplane. The Etrich monoplane is the result of a lengthy study of bird-wing structure, Etrich beginning his experiments in 1898 by acquiring the Lilienthal glider. He made extensive studies of the propulsive organs of every form of flying animal, birds, insects, bats, the flying fish, even extending his investigations to the vegetable kingdom by studying the various forms of flying seeds, such as those of the sycamore and the pine.

The wings of the Etrich monoplane are what he terms of the "zanonia" form, and were previously tried out very thoroughly in a glider, the experiments with the latter dating from 1904. As will be apparent in Fig. 47, the front part of each wing is rigidly constructed of webbed ribs, built over three longitudinal spars, of which the forward one forms the leading edge. These sections are double surfaced, *i. e.*, covered on both sides with a rubberized fabric. Behind the rear beam extend bamboo continuations of the ribs which are covered with a single surface of fabric and form a flexible trailing edge. The flexible wing tips are turned up at the rear within and so give both wings an effective negative angle of incidence. It is to this feature that the Etrich owes its pronounced degree of inherent stability. Lateral balance is maintained by raising either wing tip by means of a cable, which, passing over a pulley situated at the top of the king post, divides up into eight wires connected to the flexible extremities of the wing. A cable passing over the lower end of the king-post lowers the opposite tip a corresponding amount. Enormous strength is imparted to the wing by a bridge-like structure of steel tubing, which embraces the middle-wing spar and is attached below the under surface, which renders the wings capable of withstanding strains many times in excess of those they are likely to be called upon to bear in flight.

A small wheel mounted at the lower extremity of the king-post protects the wing tip from contact with the ground. The bird tail pivots in one unit about a horizontal axis, the rear portion of this tail forming the elevator, which is controlled by warping the horizontal tail plane. Two small, triangular vertical rudders, one above and the other below the horizontal tail plane, are hinged to the rear edges of two triangular stabilizing fins and are operated by pedals in front of the pilot's seat, these being plainly apparent in the plan view of the machine, Fig. 47. Elevation and lateral balance are controlled by a rotable hand wheel placed on the top of a vertical column. The chassis is similar to that of the Bleriot with the addition of a movable,

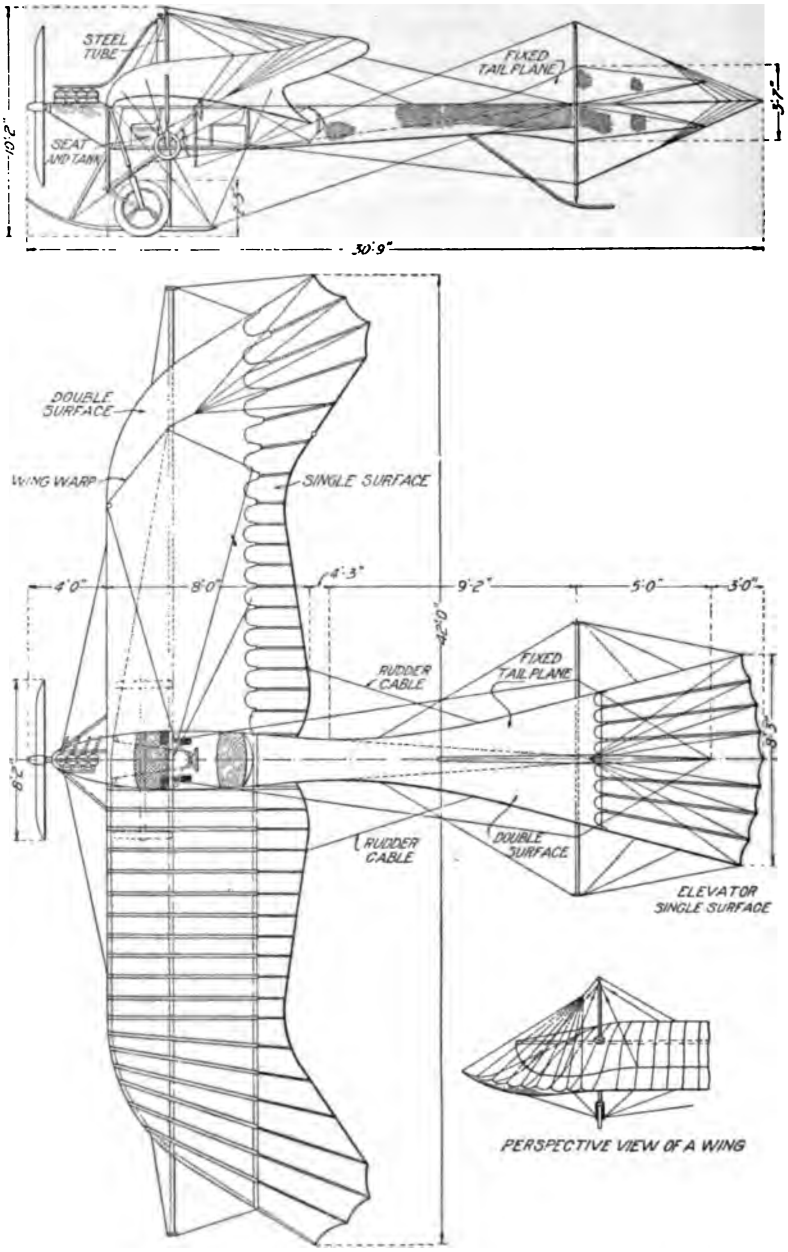


Fig. 47. Diagram of Etrich Bird-Wing Monoplane

central, ash skid which is controlled simultaneously with the rudder by a pedal. The wheels are pivoted so that the machine may be steered when on the ground.

The body is a fish-shaped structure of four wood longitudinal spars, cross braced by wire guys. From the engine bed, which is mounted at the forward end, the body deepens and widens in the vicinity of the pilot's seat, from which point it gradually tapers, still preserving its triangular section, until the tail is reached, where it terminates in a vertical line. To avoid internal disturbance in the air discharge, the body is covered forward with aluminum sheeting and aft with fabric. The radiator is an inverted **V** suspended above the passenger's seat, its height above the motor securing effective thermo-siphon circulation in case the centrifugal pump becomes deranged. The Etrich machine illustrated is fitted with a 60-horse-power, four-cylinder motor, while other types of the same are a 120-horse-power, three-passenger monoplane and a racing machine of 60 horse-power. Etrich has also built another novel type with bird-form wings termed the "swallow."

Queen-Martin Biplane. The Queen-Martin biplane, Fig. 48, is an American machine and is a representative of a type that is now becoming numerous. It is really a cross between a monoplane and a biplane, the main structure being patterned after the Wright system, while the placing of the motor and the arrangement of stabilizing and controlling surfaces are similar to the Bleriot, being carried on the end of a long fuselage. The spread is 30 feet, with a chord of 5 feet 1 inch, the planes being single-surfaced and having the ribs slipped into pockets sewed in the fabric. The planes are spaced 5 feet apart vertically and the struts are held in brazed steel sockets, double guyed with nickel-plated, flexible cable. The main beams are of ash and of square section, with simply enough rounding of the edges to prevent cutting the fabric, the ribs being screwed to the top of the forward beam and to the under side of the rear one. There are three sections to each plane, the ribs at the junction points being of square box construction with intervening solid ribs of rectangular section. Near the center is a **T**-rib of the Farman type, while the outermost ones at the extremities of the planes are of the usual **L** design. Spruce is used for the struts, except in the center section, and also for the small ribs, the box ribs being elm. The sections are joined by lengths of square steel tubing fitting over the ends of the beams and bolted. The fuselage is in two sections joined by square steel sleeves, the aviator's seat being in the forward section just at the trailing edge of the lower plane. Under this seat is placed a

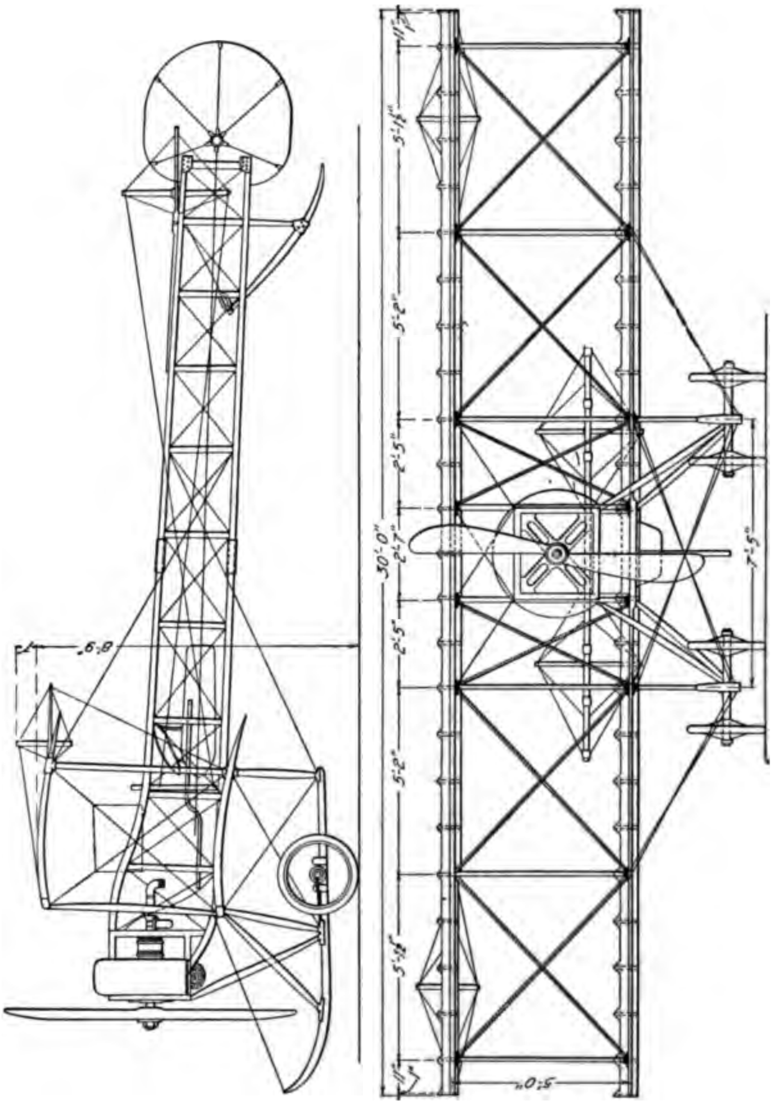


Fig. 48. Queen-Martin Biplane with Motor Forward of the Operator

large supplementary gasoline tank, from which fuel can be transferred by the aviator to the gravity tank in front of him. The aviator has to look over the gravity tank as is the case in a monoplane. Lateral control is by means of positive acting ailerons hinged to the rear upper beam operated through a gate control of the Burgess type, as shown in the longitudinal elevation, Fig. 48. Either hand may be used when it is desired to rest the other.

The elevator is in two parts and each half operates in conjunction with the ailerons on the same side, though in the proportion of but 1 to 6. The aileron cables have a certain amount of slack to avoid any turning movement of the aeroplane, also to avoid unequal pressures on the ailerons. The vertical members of this gate control are universally pivoted to permit of working the elevator in that capacity alone.

The tail or rear stabilizing surface is a perfectly flat, semicircular plane fixed in place. Hinged to the rear edge of this are the two elevators which are also semicircular in shape. They are operated simultaneously by a fore-and-aft motion of the gate control through crossed cables. Both of the elevators are double surfaced and they are separated by the width of the fuselage. The rudder is of semicircular form, double surfaced, and is hinged directly to the rear end of the fuselage. It is operated by a foot yoke through cables running in guides fastened to the struts of the fuselage. The machine is said to be possessed of such a high degrees of inherent stability that the ailerons do not have to be used in ordinary weather, and by stopping the motor it immediately assumes its gliding angle of 5 degrees. The power plant is a 100-horse-power Gnome, fourteen-cylinder revolving motor driving a propeller 8 feet 3 inches in diameter by 7 feet 6 inches in pitch, the ignition wiring of the motor being so arranged that the aviator may short-circuit seven of the cylinders when it is desired to cut down the power. A second switch cuts out the second set of seven cylinders. The large, horizontal tank is divided into two equal compartments, one for gasoline, and the other for castor oil, the latter being fed directly with the fuel to a Gnome motor in the proportion of about 1 to 5. Ash skids are used in connection with the usual rubber, spring-mounted wheels on the running gear, a hickory skid being placed under the tail. The weight with fuel and oil is 950 pounds, sufficient of the latter being carried for a 5-hour flight. Instead of being designed to fly at a certain angle of incidence, the Queen-Martin biplane depends entirely upon the camber of its surfaces for its lift, which is very small, not exceeding 2½ inches.

Albatross Biplane. As its name indicates, the design of this machine is somewhat similar to that of the Etrich monoplane, in that it has flexible surfaces patterned after a bird's wings, but the idea is carried further by extending the same principle to the tail. Like the Queen-Martin, it has a monoplane body and a single tractor screw forward, but the fuselage, instead of taking the usual form of a rearward-tapering box girder of lattice construction, is flattened and broadened out just behind the lower main plane to form a support for the tail which is a horizontal triangle, similar to that of a bird. The vertical rudder, in the shape of an elongated fin, is placed directly above the center of the tail, while the flexible rear end of the latter serves as an elevator, exactly as it does in nature. The use of a flattened fuselage at the rear with a rudder above the tail and the elevator at its extremity was inaugurated by Bleriot in his racing machines in the summer of 1911. It has proved so efficient that it has since been adopted by a number of the leading foreign manufacturers and is a feature of the Bleriot French army machines. In the Albatross, which is of German manufacture, the lower plane is very much smaller than the upper, while the struts between them are placed diagonally, thus eliminating the use of the usual numerous stays and wire braces. The ends of the upper main plane taper to a point in the form of a bird's wing and for several feet from the end they are flexible, this use of flexible wing and tail surfaces doing away with all supplementary stabilizing planes, the area of the tail being unusually large, while its supporting effort, instead of being utilized merely at the end of the lever, is extended to a point just back of the lower main plane. More than twenty of the Albatross biplanes have been made for the German army.

Breguet Biplane. Breguet was one of the first French constructors to adopt the arrangement originated by the Wrights of running a large diameter propeller at low speed, and he was also a pioneer in the introduction of the biplane with a monoplane type of body and placing of the power plant. The unusually high efficiency gained is evidenced from the fact that with an ordinary two-passenger biplane he has carried six persons of a total weight of 924 pounds, which is very close to that of the weight of the machine itself—1,045 pounds—while his racing machines have also proved unusually speedy. The span is 43.3 feet, but the lower plane is only 32.5 feet wide, with a chord of 5.6 feet. A five-cylinder, semi-radial R. E. P. motor of 50 to 60 horse-power drives a two-bladed propeller 9.5 feet in diameter and of variable pitch through reduction gearing. The entire fuselage is enclosed with fabric, and the combined rudder and elevating plane in the form of a cross are hung from its after end on a universal joint. Control is by means of a wheel placed on a column, as in the Curtiss, revolving the wheel causing the rudder to turn, while pushing or pulling on it moves the column back and forth and actuates the elevator. Pushing the wheel from side to side flexes the wings, thus centering the control on a single lever. With the motor in question, its speed is 53 miles per hour, but a special racing type with only 280 square feet of supporting surface and a higher-powered motor is also made.

Tubavion Monoplane. Very radical departures from accepted standards of monoplane construction are found in this machine. A long steel tube forms the backbone and replaces the usual monoplane body, while converging, upward-curving skids are attached to this tube at the front and rear, thus making what is practically an "underslung" type, the motor being placed forward under a bonnet closed in front by the radiator, as on an automobile. The propeller is mounted on the main steel tube forming the backbone, just back of the main plane, and is chain driven from an extension of the engine shaft which runs back beneath the pilot's seat, thus giving an arrangement of the motor in front and the propeller at the rear. In fact, the power plant has been brought right up to date by providing the motor with a self-starter, so that it may be re-started in the air in case of accidental stoppage. The pilot sits directly behind the motor. Several machines built on this general principle, *i. e.*, monoplanes with a small underslung car in place of the usual monoplane body, made their appearance at the Paris aeroplane show late in the winter of 1911.

Morane Monoplane. While this machine is in general based upon Bleriot lines, Morane having been an associate of Bleriot's for some time, it is noticeable for the entire suppression of the dihedral angle between the two wings and their flatness on the under side, this having been planned to increase the speed. The shape of the ends of the wings has also been radically altered and their point of maximum camber placed very close to the leading edge. The mast carrying the upper wing stays is pyramidal and is so arranged that the support at the front is more at right angles to the wings and so better protects the spars from over stress. The rudder is divided into two sections by the stabilizing tail, just forward of which is a light double skid. The pilot sits behind a long bonnet enclosing the tanks and extending over the engine, in the type employed in the long-distance races in the summer of 1911, but at the Paris salon in December of the same year, Morane exhibited a strikingly novel machine of all steel construction. The body is made of pressed steel in torpedo shape, *i. e.*, ovoid forward and tapering to a sharp point aft with a perfectly smooth finish outside, and as bracing is done on the interior this cuts the head resistance to the minimum. The Gnome revolving motor is completely enclosed with a comparatively small number of openings for cooling it, the propeller being the only part of the power plant that is visible from the outside. The use of steel tubing for the beams and ribs of the wings also does away with practically all braces and guys, so that the machine should prove exceptionally fast, even as compared with its immediate predecessor, which showed an average of 70 miles an hour on a closed circuit with a 50-horse-power motor. The chief dimensions are: Span 31 feet 6 inches; length 22 feet 6 inches; supporting area 188 square feet, of which 151 square feet are in the wings and the remainder in the stabilizing tail. Some idea of the care that has been taken to reduce weight is evident from the fact that the complete machine empty weighs but 440 pounds, and this has not been attained at the sacrifice of strength, as the machine is very solid. Among the speed performances of the Morane are the covering of 210 miles in 2:12, or at the rate of 90 miles an hour with a 20-mile favoring wind; 500 miles in 6:55, or 72.28 miles for the entire distance, and the winning of the Paris-Madrid race, the start of which was marked by the killing of two aviators and two French officials of prominence. In this race the Morane driven by Vedrines was the only aeroplane to finish, capturing the prize of $20,000.

Deperdussin Monoplane. While apparently a small machine, the Deperdussin has unusual carrying capacity and high speed with heavy loads, holding all world's records up to the end of 1911 for 4 and 5 passengers for distances up to 30 miles. Two of these monoplanes were brought to this country in the summer of 1911 and have made an excellent showing at various aviation meets. It is said to be one of the easiest machines for the beginner in which to master the difficult art of flying, and for this reason they have been employed to a great extent by schools on the other side. The wings are similar in shape to those of the Antoinette and, in fact, the entire machine resembles the latter to some extent. In the regular passenger and school machines, the wings are set at a slight dihedral angle and there is a perfectly flat triangular tail plane; but in the racing machines the planes are flat and the tail is of the lifting type. As there is every reason to believe that the non-lifting tail is the more efficient for a machine of this kind, the precise reason for the employment of a lifting tail is rather obscure. The elevator is hinged to the rear of the tail plane, while forward of the rudder extends a small stabilizing fin. The control is one of the best points of the machine, giving the greatest possible amount of freedom to the pilot. Instead of the usual arrangement of a vertical lever between the pilot's knees, the Deperdussin has two side levers connected by a pinned crosspiece on which is mounted a hand wheel. The rotation of this wheel corrects the lateral balance, while a to-and-fro movement controls the elevator, steering being effected by a foot lever in the manner common to French monoplanes. The cables from the warping control are carried down to a T-shaped lever mounted on the rear crossmember of the chassis and, after passing over pulleys on the skids, branch out into two wires each and proceed to two points on the spar of each wing. By rotating the wheel to the right, therefore, the whole of the rear spar of the left wing is pulled down, while the similar spar on the right wing rises a corresponding distance, and *vice versa*. Very little wire bracing is used on the landing chassis, rigidity being given to the structure by two wood diagonal struts in compression, the forward portion of the skids being an extension of these struts, and is connected to the skid proper by a thin band of steel to prevent the upturned front part of the skid from letting the machine down too heavily in the event of a sudden landing. A peculiar feature noticeable on the racing type is that the big tractor screw comes below the skids when in the vertical position, so that it is almost certain to be smashed in the event of a rough landing. Two Deperdussin monoplanes shared the honors with the Nieuport by being the only three monoplanes to meet the severe conditions imposed by the French military authorities in the 1911 competition.

Valkyrie Monoplane. The Valkyrie is one of the few English machines of this type. It is a peculiar combination of monoplane and biplane features, resembling in one respect the Voisin canard type, by having the elevator and a pair of stabilizing fins way forward of the main planes, and in another, the original Wright machine, in that the elevator is forward and the vertical rudder aft of the main planes, though structurally it does not resemble either of these types particularly. The main planes are in three sections, the center one being given a shorter chord than the other to allow room for the propeller, while the two outer sections are set at a pronounced dihedral angle. There is also a longitudinal dihedral angle between the main planes and the forward fixed plane, which is placed above the elevator and is given an angle of incidence of 9 degrees, while that of the wings is 13 degrees. The front fixed plane is placed 11 feet 9 inches forward of the main planes and its angle may be varied to compensate for changes in the loading. The elevator, which is below and at the rear of the forward fixed plane, is characterized by a slightly upturned trailing edge. All planes are of the single surface type and of Farman construction. Lateral stability is secured by the use of flaps at the extremities of the wings, but warping can be used. Twin vertical rudders some distance apart and placed three feet back of the main planes are employed. It has been found necessary to fit "blinkers," or small vertical fins similar to those used between the forward braces on the Wright, as without them, when making a short turn, the machine was likely to turn completely about its radius of gyration and come to the ground in a heap. The running gear is of the Farman type.

Hanriot Monoplane. The Hanriot is another French monoplane that has made such a favorable name for itself abroad that plans have been made to produce it in this country, the monoplane being a type that has not been particularly developed in America, unfortunately. There are many points of distinct originality in the Hanriot design and construction. Chief among these is the wood, boat-shaped hull, supported on three A-frames from the chassis, which makes a remarkably simple and strong construction, while the boat-like body dispenses with the usual great amount of wire necessary to brace a girder or box frame. This body is almost a replica of the usual racing scull, being entirely decked in except for a small cockpit to accommodate the aviator and the controls, this deck being made strong enough for the aviator to stand upon. Three steel ribbons form a support for the body on the A-type chassis frame, and steel tapes are also employed for lashing the main spars of the wings to the body. These spars are laminated, a form of construction that overcomes the usual tendency of the monoplane spars to buckle. The E. N. V. eight-cylinder, V-type, 40-horse-power motor is carried well forward of the main planes, where it is mounted on the bow of the boat body, and is also partly supported by the struts of the A-framing of the chassis. An unusually large rear stabilizing plane is employed, measuring 9 feet 3 inches in depth by 8 feet in width, in the form of a triangle. Two elevating planes are hinged to the rear edge of this fixed plane, with a space for the rudder between them. The span of the main planes is 30 feet and the chord 7 feet and they are set at a dihedral angle of 1 in 25; their total area is 184 square feet. This fixed tail plane is quite flat and consists of a single surface stretched tightly by the aid of two transverse spars. Its rear portion is deflected a little below the line of the leading edge, to which it has a relative though small angle of inclination.

Curtiss Racing Machine. In developing a racing machine, the Wright Brothers have proceeded along exactly the same lines as in their regular type of machine, high speed being obtained by cutting down the supporting surface and increasing the power. The Curtiss racing machine, however, is a special type, in that it is not exactly either a biplane or a monoplane. As will be apparent from the photograph, Fig. 49, it is a cross between the two and is accordingly in a class of its own. So far as its main supporting surface is concerned, it is a monoplane; but, placed centrally above this main plane, is another but very much smaller plane which resembles a canopy more than anything else. This small upper surface is not employed merely for the purpose of obtaining additional supporting area, but simply to take advantage of the support afforded by the tubular, vertical struts for the attachment of the guy wires. The elevating plane is placed in front but quite close to the main plane, and it is a single surface instead of the usual biplane cell employed on the regular Curtiss machine. There is also a rear plane, but instead of arranging this to move, its rear edge is made flexible and it also acts as an elevator, thus providing the machine with an elevating rudder both front and rear. The running gear, as will be apparent, is closely modeled after the customary Curtiss standards, but the framework, instead of being of bamboo or light wood, is largely composed of steel tubing.

The usual balanced vertical rudder is placed at the rear and small vertical keels are used forward to offset the effect of side winds on the rudder. The wings are rigid and are fitted with hinged ailerons as in the Farman type. These ailerons have a spread of 6 feet 2 inches by a depth of 20 inches and are operated by means of cables attached to a shoulder brace as in the regular Curtiss machine.

Fig. 49. Curtiss Racing Machine. This is Practically a Monoplane

The main planes have a spread of 29 feet and a depth of 4 feet 6 inches, giving an area of 120.5 square feet. The front elevator measures 6 feet 2 inches by 2 feet 8 inches, while the rear elevator has a spread of 8 feet 2 inches and a depth of 2 feet 10 inches, the rear edge, which can be flexed, having a depth of 20 inches. This makes the total supporting area of the machine 160 square feet, exclusive of the small upper plane.

The mottor is an eight-cylinder, four-cycle V-type, water- instead of air-cooled, the valves being placed in the heads of the cylinders. The cylinder dimensions are, bore 4 inches, stroke 4½ inches. It weighs 250 pounds all told and develops 70 horse-power. Lubrication is by means of a rotating vein oil pump, the supply being carried in a wedge-shaped tank below the motor. The radiator is placed forward of the motor and just behind the aviator. Mounting is on three 12-inch wheels shod with heavy pneumatic tires, while instead of the spoon brake employed on the front wheel of the regular Curtiss machine, two sprags are attached to the main axle. It was found that the front wheel bore such a small part of the weight that a brake was not effective. These sprags are brought into operation by an extreme forward movement of the vertical steering wheel, the remainder of the control consisting of a foot-operated throttle for the motor, and the working of the ailerons by the shoulder braces, the turning of the steering wheel governing the vertical rudder. The propeller is of laminated spruce, 8 feet in diameter by a 6-foot pitch, and is attached directly to the crank shaft of the motor.

The front control is placed 8 feet forward of the main plane, while the rear control is 14 feet back of it, giving the machine a total depth of 26 feet overall. Very little wood is used in the construction of the framework, thin steel tubing predominating, while the surfaces of the planes are composed of the thinnest racing yacht sail cloth. This is the Curtiss machine that was designed and built to compete in the Gordon-Bennett contest at Belmont Park in the fall of 1910, but which was finally not entered.

Multiplanes. It will be noted that neither in the article on "Standard Types," nor in the present one, has any mention been made of machines with more than two independent surfaces. In fact, all of the machines that have been successfully flown to any great extent thus far, have either been biplanes or monoplanes. One reason for not attempting to use more than two planes is to be found in the greater complication involved in the construction, as well as the introduction of a new factor brought about by the increase in the height of the machine—that of vertical stability. With good control of the lateral stability by warping or ailerons, and of longitudinal stability by means of the tail and elevating rudder, the aviator can safely disregard this third factor. Unless something happens to the machine it is in no danger of assuming an angle of inclination to the horizontal that would tend to rob it of supporting power to an extent that would make a fall imminent through the aeroplane "standing on its head," or the reverse. With the towering structure represented by three or more superimposed planes, it appears as if a sudden gust of wind—a sharp puff that happened to strike the upper planes and not the lower ones, as is quite possible, or a strong slant of wind that exerted considerably more pressure upon the upper part of the machine than it did on the lower—would be quite likely to cause this result. It will be recalled that the Wright Brothers give it as their opinion that no advantage is to be gained by increasing the number of planes above two.

Roe. However, so many obvious theories that apparently can not fail to hold good in practice have been upset by the results obtained in flights with various types of machines, that it is difficult to put any of them down as entirely untenable until this has been demonstrated by experiment. Unfortunately, most of the experiments with multiplanes so far have not resulted successfully. Some, on the other hand, have given considerable promise but have been carried out only on a small scale. The first public appearance of a triplane was at the Harvard Aviation Meet, in September, 1910. The machine was designed and built by A. V. Roe, an Englishman, who also attempted to fly the machine. As will be apparent from the photograph of this machine, Fig. 50, it is practically a Farman biplane, with the addition of a third plane of smaller dimensions placed below the other two. The tail is likewise a triplane. Control of lateral stability is attained in the same manner as in the Farman, *i. e.*,

Fig. 50. Roe Multiplane

by ailerons or wing tips, but these are attached to the rear surfaces of the middle plane instead of to the upper plane as in the French machine. The motor is mounted at the forward edge of this central plane with the direct-connected propeller placed in front, while the aviator's seat is placed in the framework about on a level with the third or lowest plane. The construction of this frame is somewhat similar to that of the Bleriot. The machine is mounted on two pairs of pneumatic-tired wheels attached to long skids, as in the Farman, while a third small skid is placed under the elevating rudder. On the only occasion on which the Roe triplane was used at the Harvard Meet, it made a short flight, Fig. 51, and then dove to the ground, wrecking itself. As many successful machines have performed in a similar manner in the hands of unskilled aviators, this does not necessarily imply a fault in the design, nor for that matter a lack of skill, as something may have gone wrong with the control.

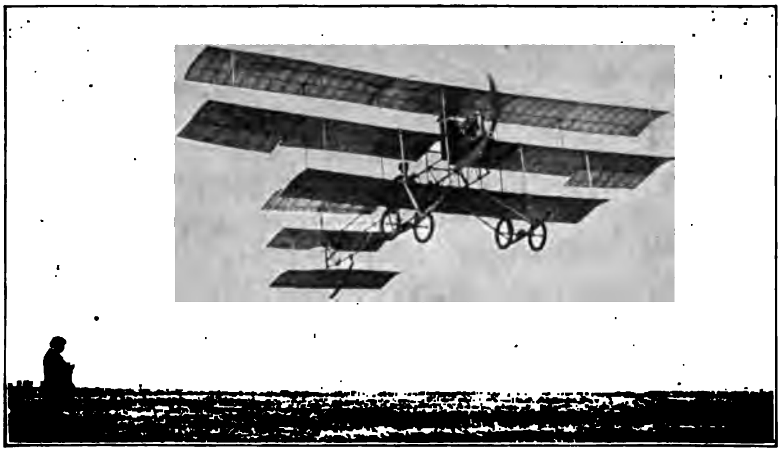


Fig. 51. Roe Multiplane in Flight

Roe has been a persistent experimenter with the triplane and worked at the problem for a long while, developing his first machine in which he succeeded in getting off the ground. This was practically a Langley aerodrome in triplicate and not the machine used at Boston. The three planes were of the same area and were attached to three similar but smaller planes, forming the tail by means of a triangular frame. It was mounted on two wheels forward under the main planes and a skid at the rear, the aviator sitting in the body or enclosed frame about midway between the main planes and the tail. The forward or main supporting surfaces measured 20 feet in spread by a depth of 3 feet 7 inches, while the rear planes were of the same depth with exactly half the spread, or 10 feet, giving a total area of 320 square feet. The motor of but 10 horse-power was mounted originally at the forward end of the framing and carried a three-bladed propeller directly on its crank shaft. With this motor the total weight of the machine itself was but 200 pounds, or with the aviator, about 350 pounds, thus lifting 35 pounds per horse-power. Subsequently, a 20-horse-power motor was installed and the weight of the machine considerably increased. The body is constructed of deal (spruce) and is covered with oiled paper backed with muslin. Instead of the usual elevating rudder, the machine is caused to ascend or descend by altering the angle of incidence of the main planes themselves, all three being pivoted for this purpose. The transverse control consisted of warping the rear edges of the main planes in the usual manner and at the same time employing the vertical rudder at the rear. With this machine, a number of short flights in a straight line were made, the most striking feature being the low power necessary.

Sellers. From similar experiments made in this country, the possibility of greatly increasing the efficiency as represented by the present-day standard appears to be the chief promise held out by the multiplane. M. B. Sellers, a Kentuckian, has made extended experiments in this direction with a quadruplane and has made a number of flights, using a Bates two-cylinder opposed motor rated at but 10 horse-power. The four planes are not placed directly above one another, but are joined in the form of a parallelogram with a forward inclination from the vertical in the direction of the machine's flight, thus bringing each surface slightly in advance of the one below.

Zerber. Another type, the Zerber, is shown in Fig. 52.

Paulhan Triplane. Paulhan has brought out a triplane of the same construction as the box-girder type already described, but trials made with it during the summer of 1911 were not successful.

Maxim. A machine that probably conforms less to the standards already set forth than any other is the new Maxim aeroplane, about the construction of which considerable secrecy has been maintained. It is, in fact, the Maxim flying machine of almost twenty years ago brought down to date, every part of it, even including the motor and propellers, being made by the inventor himself, in accordance with his own theories. His first care was to reduce the proportions of the machine as compared with the gigantic apparatus built at a cost of $100,000 in 1894. The spread of the new aeroplane is but 44 feet—large in comparison with most standard machines, but not when compared with the spread of over 100 feet of the original Maxim. Like its prototype, the new aeroplane is of the multiplane type and is, in effect, made up of six aeroplanes, each being 6 feet 6 inches in depth, giving it an aspect ratio of 6.77. The planes are noticeably thin and consist of waterproof silk, very tightly laced on. From the central plane spring out two superposed wings, raised well above it, and so curved as to produce inherent lateral stability to a very high degree.

Fig. 52. Zerber Multiplane

There are balanced rudders fore and aft and a horizontal steering rudder, the Maxim patent device for altering the pitch of the planes when in flight being utilized. This differs from the Wright warping device in that the wings are moved in one direction by a lever worked by hand, while a spring controls them in the reverse direction.

The engine is mounted between the planes and behind the pilot, who sits in a low, metal-covered compartment, with the steering and control levers directly in front of him. One of the most novel features of the machine is its power plant and drive. On the engine shaft is one small propeller, mounted at the rear of the planes. This screw turns at the same rate as the engine shaft and also serves as a fly-wheel. In addition, there are two large propellers, 11 feet in diameter, mounted higher up between the planes and driven by steel cables kept taut by idler pulleys. The small screw and one of the large ones rotate in the same direction, while the other large one turns in the opposite direction. This screw is also given a finer pitch and a higher velocity than its companion and in this way its gyroscopic action balances the joint gyroscopic action of the other two propellers, rotating in the reverse direction.

The motor is a four-cylinder, vertical, water-cooled type of 60 horse-power, built throughout of a special grade of Vickers steel, making it amply strong but very light. Special attention has been paid to the valve and carbureter design and a greater degree of reliability is claimed for the engine than those usually employed in aviation. An ingenious force-feed system of lubrication is employed which carries oil to every working part of the motor in a very effective manner. The radiator is mounted under the upper plane in a manner somewhat similar to that employed on Santos-Dumont's Demoiselle.

The whole machine is mounted on wheels and shock absorbers. There is a noticeable absence of the complication of stays, guy wires, and framework common to the usual biplane construction, and which causes so much head resistance. The grouping of the various members has been skillfully carried out, those parts creating the greatest resistance being set as far as possible in line behind one another. Like its predecessor, it has also been experimented with in a captive state, but instead of the tracks on which the first Maxim machine ran, an apparatus similar to that designed by Captain Ferber is employed. This consists of a mast with a huge revolving arm, permitting the aeroplane to fly in a circle round its support. When so many other new machines are experimented with in free flight by aviators of little or no experience, the Maxim method scarcely appears necessary, though it at least has the virtue of greater safety.

Steel Tube Construction. That there is likewise ample room for improvement in constructional details will be obvious upon a consideration of the methods and materials employed in building the standard types of aeroplanes already described. Crudity was to be looked for at first—many successful experimenters had neither the means nor the facilities to employ special materials or construction. They were in much the same position as early experimenters in the automobile field. But now that so much has been done in the development of steels and light alloys of tremendous strength for automobile construction, there appears to be no reason why they should not be taken advantage of to replace the more cumbrous and none too safe wood or bamboo framing. Two instances of this are shown in Figs. 53, 54, and 55. Many of the new machines produced during 1911 employ steel tubing to a greater or less extent.

Fig. 53. Fairchild Monoplane with Frame of Steel-Tube Construction

Fairchild Monoplane. The Fairchild (American) is one of the few types of monoplanes extant, employing two propellers. It is, in fact, a model of mechanical construction, and if its flying capabilities are in any way commensurate with the intelligence and resourcefulness displayed in the working out of its design, it would seem to presage the advent of the eminently successful American monoplane.

Fig. 54. Henri Farman in His New Monoplane. The Frame is of Steel-Tube Construction

The frame is of graduated steel tubing, lightness with maximum strength having been obtained through the use of different diameters and thickness of tubes, the necessary strength of each part having been carefully calculated in detail. Wherever special strength is required, the tubes are forced over elm poles. In the trussing of the frame, steel tape and cable are employed in place of the usual piano wire, which, though very strong, is an uncertain factor and likely to give way unexpectedly.

Fig. 55. Front View of Farman Monoplane

The wings are of the usual monoplane type and are built up of 14 double ribs over transverse 1-inch steel tubes. They have flexible curved tips which are balanced for a certain lifting effect, but which can not be controlled by the aviator. The tail is similar to the flat type of the Antoinette and is employed solely as a stabilizer, its lifting capacity alone being equal to sustaining itself and the weight of the framework attaching it to the body. Vertical and horizontal changes of direction are obtained through rear rudders of the Antoinette type, except that a further vertical rudder in front of the hinge, in prolongation of the rear one, occupies the position of the French machine's fixed, vertical fin. Efficient lateral control is expected from a novel and very radical device, the construction of which the builder did not wish to reveal at the time.

Like the Bleriot XII, the Demoiselle, and the Grade, the Fairchild monoplane has its center of gravity comparatively low, but unlike these machines, the aviator sits above. It is anticipated that any tendency toward oscillation produced by thus placing the center of gravity low will be overcome by a large, vertical fin placed directly over the center of the machine between the main planes, as well as the fact that two propellers are employed for propulsion, or rather traction, as both will draw the machine, and both are designed to revolve in the same direction—contrary to all precedent in this field. Fairchild holds that if the gyroscopic effect of a single propeller can be deemed negligible in the monoplane, that of two is even more so. These propellers have a 7-foot diameter and a 6-foot pitch.

The motor is a six-cylinder, two-cycle Emerson rated at 100 to 125 horse-power. It is of a special four-port type and is said to show great efficiency, having developed in excess of 134 horse-power on a brake test. It is mounted at the lowest point of the main frame below the center of the wings and just above the landing chassis which is exceptionally wide and strong. A pair of pneumatic-tired wheels support the fore part of the machine when on the ground, the supporting columns, which are double, forming part of the frame; the forks carrying the wheels are hinged to the lower ends of the tubes and the wheel hubs are stayed independently to loose collars that ride upon a portion of the upper ends of the columns. These collars are anchored to the lower ends of the columns by a pair of powerful compression springs. Skids, normally 3 inches off the ground, are depended upon to absorb any excess shock, while light double skids support the tail.

The wings have a spread of 37 feet and a depth of 8 feet 4 inches where they join the body, giving it the low aspect ratio of but 4.45 to 1. The supporting surface measures 280 square feet, but despite these large dimensions the total weight of the machine scarcely exceeds 700 pounds, which is a tribute to its construction. The curve of the wings is a composite one, worked out from calculations by the designer. The length overall of the machine is also 37 feet; the area of the fixed tail is 60 square feet and that of the horizontal rudder, or elevator, 22 square feet. The greatest care has been taken in the construction of this remarkable monoplane and the engineering skill of its builder is discernible in the many ingenious details it displays, many of them never having been employed in aeroplane construction. This machine was wrecked through an unfortunate accident that had no bearing on its design or construction. It was rebuilt late in 1911 with numerous detailed improvements.

H. Farman Monoplane. A radical departure from current methods of construction is also to be found in the new H. Farman monoplane, Figs. 54 and 55. The frame is a triangular structure united at the forward end by steel girder construction in the form of a cross, the center of which serves as the support for the shaft of the seven-cylinder revolving Gnome motor. The four main frame members are connected by suitable stanchions and are trussed with piano wire; they are not joined at the rear. The wings are not mounted directly on this framework but are carried almost 2 feet above it. This places the power plant and its accessories, as well as the aviator, on a lower level than the supporting surface. The wings are mounted on another triangular structure which also serves for the attachment of the running gear· At right angles to the longitudinal frame members are two vertical members, attached to the steel girder construction on the forward end of the frame, and mounting above the level of the wings and descending considerably below the level of the frame. From the lowest point of these two uprights are two similar members inclined toward the rear, attached to the two longitudinal members of the frame and receiving on their upper extremities the rear transverse girder of the wing. This, as can be seen readily from the illustration, forms a triangle, or really two triangles, one at each side of the frame, the apex of each being near the ground and forming the support for the axle of the running gear.

The rear plane is mounted directly on the frame with the rear portion overhanging to allow free movement, while the rudder and vertical fin are mounted above the frame, and consequently above the horizontal rudder. There are neither shock absorbers nor main skids, the aeroplane landing on two small-diameter, pneumatic-tired wheels carried on a rigid steel axle passing through the two ends of the triangles already described. A simple skid is used at the rear to prevent the tail dragging on the ground. The aviator's seat is placed in the main frame, slightly more than a third of the length of the machine from its forward end. Placed below the level of the wings, the pilot is more advantageously situated to correctly estimate his distances for landing than when seated above the wing level. This advantage is obtained without any loss of protection in case of a rough landing, as almost half the machine must take the shock before the aviator can be reached.

Lateral stability is obtained by the usual Farman wing tips, or hinged surfaces attached to the rear outer ends of the main planes, the Farman being the only successful French monoplane to employ them. The Antoinette was originally built this way, but later abandoned wing tips in favor of warping, while Bleriot, Tellier, and Hanriot never used them. The spread is 23 feet 6 inches; depth, 6 feet 6 inches; aspect ratio, 3.6 to 1, which is extremely low. The tail has about 30 square feet of surface, making the total about 190 square feet. The overall length is 26 feet 2 inches, and the total weight of the machine alone, 660 pounds. So far as can be gathered from examination, the wing curvature is the same as for the standard biplanes.

Types with Fixed Stabilizing Plane. *Herring Biplane.* As is naturally to be expected, many of the special types of aeroplanes built are designed with a view to providing automatic stability, thus circumventing the Wright patents. In the Herring machine, the modification takes the form of a number of vertical, triangular fins mounted on the upper plane, Fig. 56. Each of these vertical keels has about 2 square feet of surface and there are six of them all told, two being equally spaced on either side of the center and quite close to it, while the other two are near the opposite ends of the upper main plane. When an aeroplane tips to one side, it has a tendency to slide to the ground endwise, but as the weight is low and the keels offer resistance to this sidewise motion, the upper part of the machine is retarded, while the lower part swings over like a pendulum and equilibrium is regained.

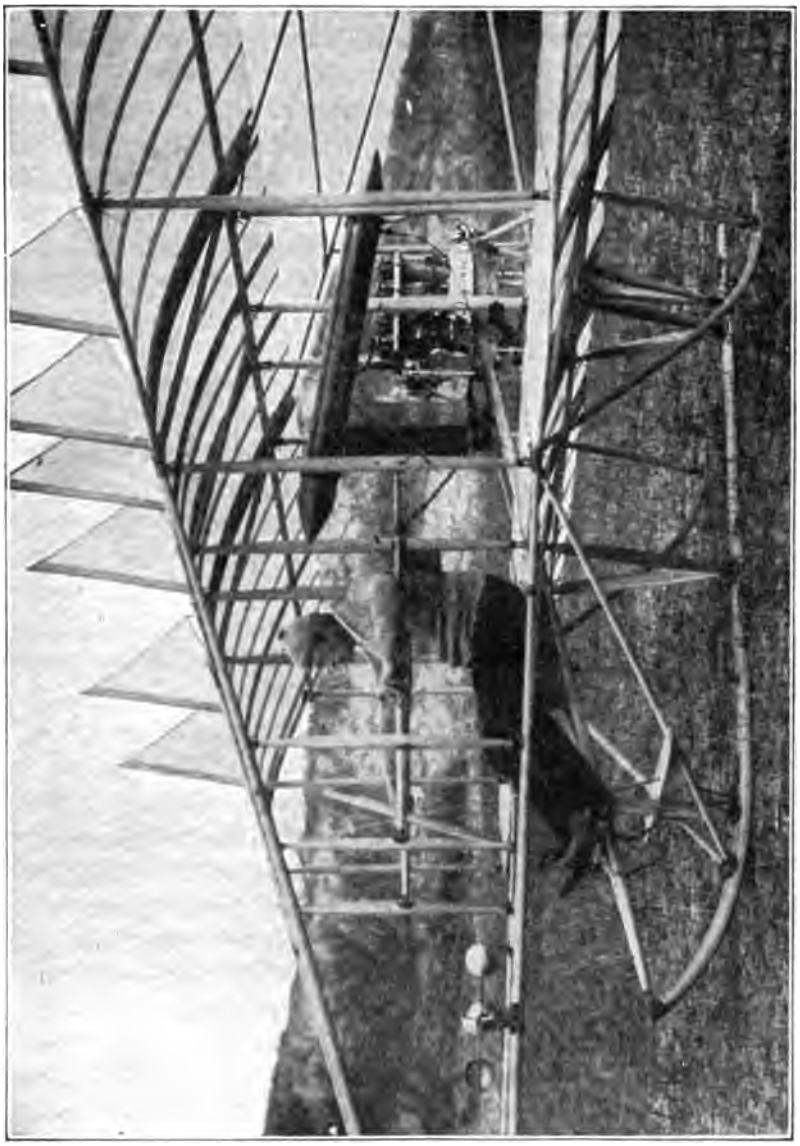


Fig. 56. Herring-Burgess Biplane Ready for Flight—Herring in the Operator's Seat

In the first test, made in the spring of 1910, the special paraffine-coated silk surfaces were very loose, owing to the dampness and fog, and when the machine was in the air it was necessary for the aviator to sit well to the left to counterbalance a difference in the lifting power of the two sides of the machine. The biplane rose readily after a run of 85 feet and is said to have taken to the air at a speed as low as 22 miles an hour. The elevating rudder was turned too abruptly and the machine shot 40 feet in the air at an angle of almost 30 degrees from the horizontal. After flying straightaway about 300 feet, the machine made a successful turn, tilting at an angle of about 20 degrees, and making a 40-degree turn. The machine weighed only 400 pounds, while the aviator weighed 190 pounds, and according to the inventor, it rose with a propeller thrust of only 140 pounds, while he believes that a thrust of 80 to 85 pounds is sufficient to fly it. On its trial flight, the motor was not run at full throttle and was thought to have developed only 9 horse-power, which would give the machine as a whole an unusually high efficiency. The method of maintaining automatic lateral stability appeared to work fairly well and is an improvement over the Voisin in that the head resistance due to the vertical keels is reduced to a minimum, owing to their form and location.

The spread of this Herring biplane is only 28 feet; depth, 4 feet; aspect ratio, 7 to 1; total supporting surface, 220 square feet. A 25-horse-power, four-cylinder Curtiss, air-cooled motor is mounted on the lower plane at the rear and carries on its crank shaft a four-bladed, 6-foot propeller of 5-foot pitch, designed especially for the machine by Mr. Herring. The total weight is about 400 pounds, or with its inventor 590 pounds, giving it a pounds-per-horse-power factor of 2.36, and a loading of 2.6 pounds per square foot of surface. The thrust obtained from the propeller at 1,200 r. p. m. is said to approximate 200 pounds. A double-surfaced elevating rudder is carried upon hollow, inclined extensions 12 feet in front, while the single-surface steering rudder is similarly placed at the rear. The machine is mounted upon a central runner having two smaller skids at each side, there also being another skid at each end of the lower plane. The aviator sits in a small seat located in front of the lower plane, and clings to two inclined braces running out in front to vertical struts connecting the poles that support the elevating rudder. The latter is operated by a foot lever, while a small lever at the right controls the steering rudder.

Baldwin Biplane. Another modification of the same scheme is incorporated in a machine built by Captain Baldwin, the dean of American aviators. This consists of the use of a single, rectangular stabilizing plane placed vertically at the center and above the upper main plane, as the Baldwin is also a biplane. This rudder may be turned about its vertical axis by means of a yoke fitting around the aviator's shoulders as in the Curtiss machine. When the machine tips, the aviator leans to the high side and sets the stabilizing rudder at an angle to the line of advance. This exerts sufficient force to bring the machine back to an even keel. The new stabilizing rudder is the result of experiments carried out by the Aerial Experiment Association several years ago and has been tried by Curtiss, who claims that it worked satisfactorily on his machine.

The Baldwin biplane has a spread of 28 feet and a depth of 5 feet; aspect ratio, 5.6 to 1; total area of main planes, 280 square feet. A small, horizontal biplane tail is carried on a triangular frame extending back of the main planes and mounted on a skid. The vertical or direction rudder is placed in the center of the horizontal rudder, or tail. The arrangement of the power plant and aviator's seat is along monoplane lines, the motor being placed at the front edge of the lower plane and the aviator's seat above the rear edge of the same plane. The flywheel of the motor extends above and below this plane. The propeller is placed half way between the main planes and is driven by a chain and sprockets. It is about 8½ feet in diameter and of high pitch. The regular Curtiss single wheel control is employed, while the mounting consists of a pair of pneumatic-tired wheels in front and a single skid at the rear. The machine has had a number of successful tests at Hammondsport, New York.

Waldon-Dyett Monoplane. Another variation of the idea of utilizing stationary keels to attain lateral stability is found in the Waldon-Dyett monoplane, a machine of American design and construction. In this case, the keels are somewhat similar in form to an old-time kite—a triangle with a spherical instead of a flat base. These keels are about 18 to 20 inches across their widest part and taper back sharply to a point, having a length equivalent to the depth of the main plane of the machine. Two of them are employed, one at each outer edge of the main plane, but contrary to the examples already described, they are set at an angle of about 45 degrees from the vertical as measured from the tip of the main plane to the keel. In other words, they both lean outward at the same angle. It will be obvious that as these keels are rigidly fixed in place, they form what may be termed "pockets" at each end of the main supporting surface. The method of their operation, or rather the rôle they are designed to play, will be equally apparent. When flying straight ahead, whether on an even keel, ascending, or descending, they are neutral. Should the machine incline to the right, it will be evident that as it goes downward on that side the lower surface of the right keel approaches more and more closely to the horizontal and interposes a correspondingly increased resistance to further inclination. At the same time the upper surface of the left keel presents a similarly increased resistance, tending to hold that end down. There is no manual control of these surfaces by the aviator.

HYDROAEROPLANES

Advantages. Ability to alight upon and rise from the water as well as from the land is a feature that the aeroplane must possess before it can be said to completely fulfill its mission. Contrary to the general impression, water is quite as hard and unyielding as solid ground when struck sharply at right angles, and the destructive effects of a vertical fall from any height would scarcely be less in striking the former than the latter, but when struck at an angle by a properly-designed surface the force of the impact is very greatly reduced as compared with a ground landing, the shock of which must be absorbed by the springs of the chassis. It is, accordingly, considered much safer to alight upon the surface of the water than it is upon the ground. But the ability to do both of these things carries with it numerous other advantages. There are few parts of the country where flights of any duration would not carry the aviator over lakes and streams, and in making long flights one of the chief concerns of the aviator is to be able to select safe landing places, so that the number available would be more than doubled. Any stretch of water, short of a swift running slant of rapids, affords an infinitely better surface than the most carefully leveled field, and when alighting in strange country, the aviator always can be certain that the surface of a lake does not hide any dangerous pitfalls in the form of grass-covered holes, rocks, and ditches that are seldom lacking in the ordinary field, and which prove so destructive to the chassis. Obstructions of a serious nature all appear perfectly flat when viewed from above so that a field which may have the appearance of a velvety lawn from a point several hundred feet over it, is quite the reverse when seen from the ground, and quick work is necessary to effect a safe landing on it. Another and even greater advantage is to be found in the fact that the wind blowing over a surface of water is much more uniform, usually being free from the uncertain puffs and gusts that characterize the same wind blowing over the adjacent land. It was doubtless for this reason that Langley selected the Potomac River as the site of the first flights of his aerodrome.

The added weight of both a landing chassis and a hydroplane float for alighting on the water naturally forms a disadvantage, but with the results of laboratory experiments now being carried out at command it will doubtless be possible to construct an aerocurve or aerfoil, as it is variously termed, *i.e.*, a supporting surface that will have such a greatly increased efficiency for the same area, that the addition of a hundred pounds or more will call for no appreciable increase in area. Constructional difficulties are also involved as the hydroplane floats must be so arranged as not to be damaged by the yielding of the springs of the chassis when landing on the ground. To a certain extent, there always will be a demand for a machine adapted to rise from and alight upon the water alone, such as the hydroaeroplanes designed for naval use, and the experiments of the past few years have been centered on the development of a machine for this purpose.

Early Attempts. While the credit for constructing the first practical hydroaeroplane belongs to a Frenchman, M. Fabre, who brought out his first machine only a few years ago, the subject was investigated in this country several years previous. This was at a time when the only motors available were unreliable automobile types, and the difficulty encountered in keeping the engine working for any length of time caused the abandonment of the experiments. Although numerous practical flights had been made over water prior to the summer of 1910, some of them of quite considerable distance, the precautions taken to insure the floating of the aeroplane in case it should drop into the water, were always of a makeshift nature, intended merely for the particular occasion. For instance, Wilbur Wright in preparing for his flight up the Hudson from Governor's Island, lashed a canoe beneath the biplane. Curtiss in his flight of 148 miles down the Hudson from Albany to New York, made use of pontoons, while in other cases air cylinders have been secured under the machine to insure sufficient buoyancy. The only instance in which the precautions proved necessary was in the case of Latham's first attempt to cross the English Channel in an Antoinette monoplane.

Fabre Hydroaeroplane. To meet conditions of this nature, Fabre designed a novel monoplane, Fig. 57, capable of starting from and alighting on the water. It can also navigate the surface in calm weather in case of damage to its supporting planes. In its construction, the Fabre hydroaeroplane differs radically from any of the other designs, in fact, it is thus far the only monoplane of its kind. The construction consists of a vertical chassis, analogous to that of a bicycle, and to which the single main supporting plane is fastened at the extreme rear. This plane is in two sections set at a slight angle, the under side of the left-hand section being shown in the figure. The motor is mounted on its after edge. Forward a biplane elevating rudder, of which the lower plane is the larger, is also attached to this frame. Immediately above the biplane rudder forward are

Fig. 57. Fabre Hydroaeroplane in Flight

two twin vertical keels, the direction rudder being placed at the center of the main plane, just where the sections join and immediately forward of the propeller, where its leverage is greatly increased by the rush of air to the latter. The aviator's seat is placed directly in the center of the frame. The cylindrical gasoline tank is placed directly behind the aviator's seat and is suspended between the guy wires of the direction rudder aft and the main longitudinal beam. Reference to the figure shows that there is less framing and less bracing on this monoplane than on any other of equal size.

The complete machine rests upon three hydroplane floats, one at the forward end of the chassis and the two others under the main plane half way between the center and the two ends. These hydroplanes are of the Ricochet-Bonnemaison type in which the bottom forms a hydroplane surface. But while, in the ricochet boats of Bonnemaison, longitudinal stability is obtained by placing one surface in front of another, and joining the two by a vertical surface forming a notch, in this case the front plane has been completely separated from the rear plane, each forming the bottom of a separate float. This arrangement has the advantage of giving both longitudinal and lateral stability, while the fact of the rear plane being divided and its halves placed some distance apart takes them out of the disturbing influence of the wake of the forward float. In addition, as each float is made up of but a single continuous surface, it has a form offering slight resistance to the air. It resembles the shape of the Antoinette monoplane wing. The resistance to the air that the notch would give is thus avoided, and the float performs a third function, since it acts as an auxiliary supporting surface when in the air. This form of float with the plane surface below and a cylindrical surface on top has the further advantage of acting like a hydroplane even though it be completely submerged. It accordingly does not offer any great resistance when engulfed by a wave, but because of its speed receives a more energetic upward impulse than ever.

The chief disadvantage of this type of hydroplane is the terrific pounding it receives when moving rapidly over water that is only slightly disturbed. The portion of the lifting plane in contact with the water, which is a strip of only a few square inches along its rear edge when the plane is moving rapidly, is instantly increased tenfold the moment the surface is no longer perfectly smooth and level, because of the slight inclination of the plane to the horizontal. The float then receives upward vertical accelerations equal to ten times its weight. To absorb these dangerous shocks, the Fabre hydroaeroplane floats have a flexible under surface. This is made up of thin veneered wood, which acts in the same way as the head of a drum. By this means, even the framework of the monoplane is protected from the shocks of the waves, in the same manner as an automobile is protected from jolting of the road through its pneumatic tires. Moreover, very great flexibility is attained between the body of the float and the heavy parts of the apparatus. As may be seen by referring to the illustration, Fig. 57, the elasticity of nearly every part of the machine comes into play to absorb the upward thrust of the waves before reaching the motor or the aviator. When at rest on the surface, the Fabre hydroaeroplane has a very slight draft, not exceeding 25 centimeters (9.8 inches), decreasing to nothing when in motion.

The tapering form of the bottom of the floats permits them to pass over weeds, ropes, and other floating bodies, or to skim over shoals without danger, even at high speed. No motor boat has such ease of evolution in shallow water as a hydroplane driven by an aerial propeller. This is true to an extent where it holds good even if there be *no water*. If the Fabre marine aeroplane should land on a meadow it would not be injured as the floats are sufficiently solid to act as skids. A device is being perfected to permit it to land or start either on the water or on the ground. The floats are capable of resisting the action of salt water, as a test, one having remained afloat for two months without damage.

The wings of this aeroplane are stretched upon a special steel truss of the same form that Fabre has employed in the Paulhan biplane just described, and the wings themselves are capable of being reefed or folded when the machine is at rest on the water as the machine might otherwise be damaged by the wind. The wing itself is composed of four parts, somewhat analogous to a bird's wing:

(1) A trussed longitudinal girder is placed along the front edge in the position which the bones occupy in a bird's wing. This is the only longitudinal support of the wing and it is depended upon to give rigidity to the whole construction so that it is very strongly reinforced. The uprights to which the floats are fastened are attached directly to it. This zigzag form of girder, which is a newly patented

construction, is used not only for the wings and horizontal rudders, but also for the members of the chassis, and for the framework of the hydroplanes; in a word, the whole apparatus is essentially a Fabre reinforced beam.

(2) The ribs which correspond to the quill feathers of a bird's wing, consist of thin strips of wood superposed and glued together. They fit into sockets on the bottom of the single longitudinal girder.

(3) The covering of the wing consists of "simili-silk," such as is used for the light sails of racing yachts. This is hemmed and reinforced at the edges and provided with eyelets and grummets, permitting it to be laced on, so that it may be quickly removed without dismounting any part of the skeleton of the wing. Pockets corresponding to the position of the ribs are sewed into the cloth and the latter is drawn on over them and then laced to the main girder, wood eyelets being employed for this purpose, while at the rear it is held taut by ingenious spring clamps.

(4) Suitable braces are provided for holding the main beams of the wings against turning in their sockets when the machine is in flight. Steel cables fastened to the lower ends of these braces serve to regulate the angle of incidence of the wings or to warp them. The wings themselves are also trussed with similar braces.

The spread is approximately 47 feet, depth 6 feet, aspect ratio 7.4 to 1, total area about 280 square feet, pounds per horse-power 5.6. The total weight in flight is about 950 pounds, giving it a loading of 3.4 pounds per square foot. The power plant consists of a 50-horse-power, seven-cylinder revolving Gnome motor, directly attached to an 8½-foot, two-bladed wood propeller which it drives at 1,100 r. p. m.

The Fabre hydroaeroplane made its first flight at Martigues, France, March 28, 1910. It attained a speed of 34.2 miles (55 kilometers) an hour on the surface, and then flew about 7 feet above the water for a third of a mile. Later it made a longer flight at a height of about 10 feet above the surface. On May 17, a series of flights were made by Henri Fabre before Paulhan. The machine rose easily and gracefully from the water and made a splendid flight of about 4 miles at a height of 65 feet. In coming down, however, the aviator volplaned at too great an angle and landed with a terrific splash, throwing Fabre head first out of his seat but not injuring him.

Under similar conditions on land, such a descent would have meant not only the total wreck of the machine but in all probability the death of the aviator. As it was, the only damage suffered was a ducking and the breakage of one end of a wing and one of the floats.

Curtiss Hydroaeroplane. The most persistent as well as the most successful experimenter in this field in America has been Glenn H. Curtiss. He first began his investigations in the early part of 1910 by attaching floats to one of his standard type biplanes, but did not find it possible to attain a speed in excess of 20 miles per hour, which was not sufficient to permit the machine to rise from the surface. Winter cut short these experiments which were carried out at Hammondsport, New York, the site of the Curtiss factory, and they were shortly after transferred to San Diego, where he was engaged at the time in instructing several army and navy officers in flying.

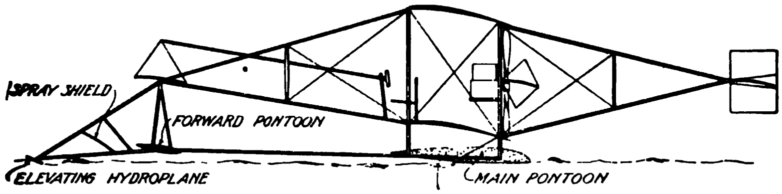


Fig. 58. Side Elevation of Early Curtiss Hydroaeroplane

First Flights. In his first experiments on the Pacific Coast Curtiss followed the Fabre design, so far as the form of the floats was concerned. One large float, or hydroplane, 6 feet wide, 5 feet from front to rear, and 1 foot thick at its central section, was constructed and placed under the center of the machine. The bottom of this float was perfectly flat and was fixed at an angle of 10 to 12 degrees. Some distance forward of the main float, at about the same position as the front wheel of the chassis of the land machine, another float 6 feet wide, 1 foot from front to rear, and 6 inches deep, was placed; while at the extreme forward end of the biplane there was mounted a small elevating hydroplane measuring 6 feet wide by 8 inches fore and aft and 1½ inches thick. This hydroplane was carried on a special outrigger and was fixed at an angle of about 25 degrees, in order to lift the forward end of the machine, a spray shield being fitted just behind it to keep the aviator dry when skimming over the surface. The location of these three hydroplanes, as well as their relative angles of incidence, are plainly shown in the side elevation, Fig. 58.

It was found that while these floats caused considerable disturbance of the water, especially at low speed, there was no difficulty in attaining a speed of 45 miles an hour on the surface. At as low a rate of travel as 10 miles an hour, the hydroplanes, which are normally submerged when the machine is at rest, rose to the surface, and as the speed increased, only the rear edges of the two main floats were required to support the machine. The aeroplane readily attained sufficient speed to rise in the air, for, as the speed increased and the floats emerged from the water, their head resistance diminished, and there were only the skin friction of the water on a very small area, plus the air resistance, to be overcome.

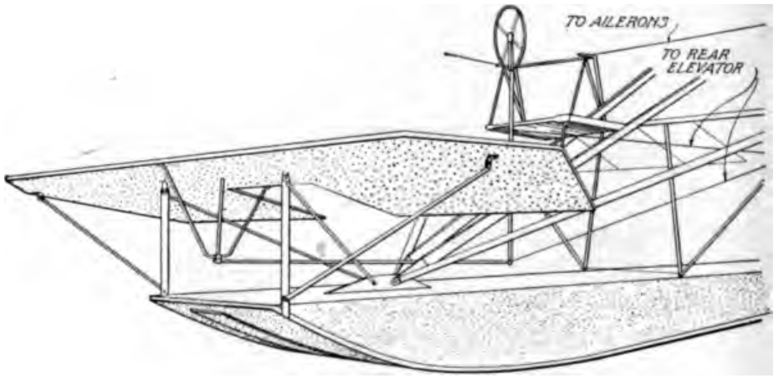


Fig. 59. Diagram of Pontoon on Curtiss' Latest Hydroaeroplane

At the first try-out, while traveling over the water at a high rate of speed, Curtiss found himself approaching the land, and to avoid running ashore, he turned the horizontal rudder sharply upward, with the result that the machine rose from the water with perfect ease. Succeeding flights demonstrated that there was no difficulty in arising from the water and alighting upon it as often as desired. The machine developed a maximum speed of 50 miles an hour in the air, as compared with 45 miles per hour on the surface of the bay. But the great fuss stirred up by these original floats as the machine got under way preparatory to rising, and the fact that they were not suited to anything but a calm surface, caused them to be discarded shortly afterward. They were replaced by a large single float, 12 feet long by 2 feet wide and 12 inches deep, Fig. 59. This was built entirely of wood and resembles a common flat-bottomed boat or scow, the top being covered with canvas to prevent the entrance of water. Three feet from the forward end, the bottom curved upward sharply, forming a smooth bow the entire width of the float, while at the rear it was inclined downward in a similar manner. This single float is placed under the biplane in such a position that the major portion of the weight of the machine and the aviator is slightly aft of the center of the float, which causes the latter to rise slightly forward when resting normally on the surface, thus providing the necessary angle for hydroplaning. The weight of the new float is but 50 pounds, or less than half that of the two large floats previously employed. Trials of the biplane fitted with the new floats showed an astonishing difference in the amount of disturbance, practically no commotion being caused even when the machine was just getting under way, while the aeroplane rose from the surface even more readily than before. Fig. 60 shows one of this type just getting under way. Besides being much more compact and creating less resistance, this new float can also be employed for carrying articles or a passenger.

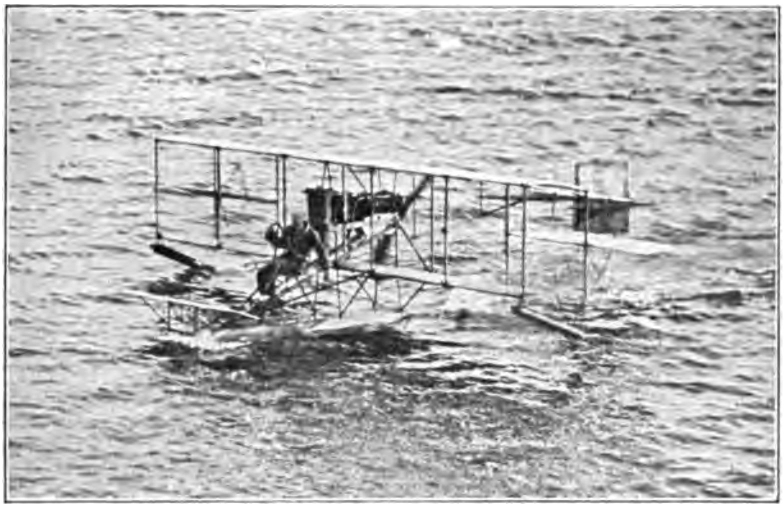


Fig. 60. Curtiss Hydroaeroplane About to Rise from the Water

In order to prevent the aeroplane from listing, or tilting to one side or the other, an inclined brace 4 feet long by 3 inches wide, is fastened to the front edge of the lower plane at each end. Attached to each of these braces is an inflated rubber tube to give extra buoyancy to the ends of the machine, should it be tilted sufficiently to submerge them when skimming over the surface. By the use of these "water props" the aeroplane is prevented from wabbling from side to side, even though the main supporting plane is but two feet in width. A number of flights made with this arrangement demonstrated the necessity of altering the balance of the biplane, and the motor and propeller were accordingly placed forward while the aviator's seat was located at the rear of the main plane, just the reverse of the standard Curtiss machine.

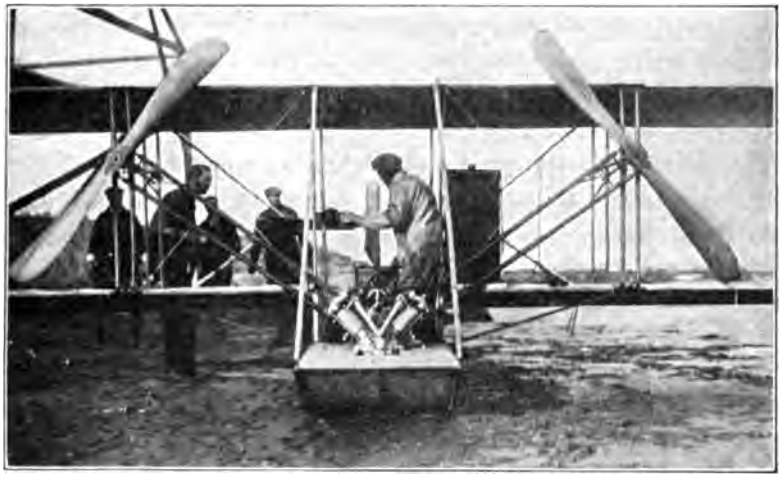


Fig. 61. Latest Model of Curtiss Hydroaeroplane Showing Two Propellers and Engine Ahead of Operator

All of Curtiss' experimenting with the hydroaeroplane was carried out with what was practically a standard biplane of his own make, mounted upon floats. As the result of the experience thus gained, he subsequently designed a machine specially for this service. This is shown in Fig. 61, and the radical departure it represents from the standard Curtiss type will be apparent at a glance. Instead of the single propeller at the rear, two tractor screws are employed. These are carried in bearings mounted on twin steel tubular struts and are driven through chains running in steel tubes by an eight-cylinder, V-type, water-cooled motor placed in the forward part of the boat or hydroplane float. Twin steel tubular struts are also employed to reinforce the structure just back of the propeller supports. The lower plane is cut away at the center and the aviator's seat is placed in the boat, bringing the center of gravity of the biplane very low. Tubular braces are run from each side of the boat to points on the under side of the lower plane, and fastened to the steel plates holding the propeller supporting struts, while bamboo braces run from the upper plane to the bow of the boat on either side, thus stiffening the entire structure. Both the elevator and the direction rudder are placed at the rear, the remainder of the construction not differing particularly from the standard Curtiss machine. Some very successful flights have been made with this hydroaeroplane.

Naval Trials with Improved Type. A great many very successful flights were made with this Curtiss hydroaeroplane as redesigned, the chief of these being the flight made by Curtiss over San Diego Bay from North Island to the U. S. S. Pennsylvania. He alighted upon the surface alongside the cruiser and the machine was hoisted aboard by means of one of the launch cranes. In addition to the reversed positions of the motor and aviator, numerous other changes were made, so that the machine is really a special type in itself. The front horizontal or elevating rudder of the Curtiss machine was removed entirely, and a special twin V-finned tail with a vertical fin in the center placed at the after end of a tail frame, similar in appearance to the *fuselage* framing of the French monoplanes. Stabilizing fins running from the lower main plane to the props already described, were also added. Special balancing planes were also placed at the rear of the main planes, half way between them and the float underneath. The removal of the forward elevating rudder made it possible to hoist the aeroplane aboard the vessel so that the aviator could climb on the deck, the modified design of the machine making it particularly adaptable for naval work, though Mr. Curtiss did not like the arrangement owing to the blast of air from the propeller constantly striking his face and the interference with his view forward caused by the new location of the motor. The demonstration so favorably impressed the naval authorities that a new machine of this type has since been purchased from the Curtiss factory and a number of naval officers were trained in its handling at Hammondsport during the summer of 1911. On one trial Lieutenant Ellyson, the navy's first qualified aviator, carried Captain Chambers, in charge af the aeronautical work of the navy, on a flight the length of Lake Keuka, a distance of 40 miles, while on a measured course the machine covered 16 miles in 18 minutes, carrying the two officers. Trials were later transferred to the Chesapeake, where Lieutenants Ellyson and Towers, of the Naval Aviation Corps, flew 140 miles from Annapolis to Fortress Monroe in two hours twenty-seven minutes, or at the rate of close to 60 miles an hour. For most of the distance an elevation of 1,000 feet was maintained. The machine was fitted with a new device brought out during the summer of 1911, which permits either the pilot or the aviator to assume control of the machine as desired. During the flight in question, the officers frequently shifted the control wheel from one to the other, demonstrating the rapidity and effectiveness with which the change could be made.

In order to utilize the advantages of the aeroplane for naval service to the fullest extent, a simple and rapid method of launching the machine from the vessel, without the necessity of encumbering the deck with special contrivances for that purpose, is essential, so that the later experiments carried out at Hammondsport with this end in view were of far greater importance than the most successful flights. Lieutenant Ellyson has devised a method by which a hydroaeroplane may be launched at sea directly from the vessel, without the loss of time necessary to put it overboard and permit it to rise from the surface of the water. Heavy seas often continue for some time after the wind occasioning them has subsided, and under such conditions, it would not be safe to launch an aeroplane from the side of the vessel, though it might be quite feasible for the machine to return alongside and be hoisted aboard, after having taken flight directly from the vessel itself. The new method simply calls for the use of cables stretched from the boat deck or superstructure of the ship, to the bow. One of these is a main wire cable down which the aeroplane slides to gather momentum for rising, while the others are merely auxiliary wires at the sides and parallel to the main cable, to maintain the machine in balance on the latter during its downward slide. These auxiliary wires support the outer ends of the wings until the machine acquires sufficient headway to maintain its own equilibrium by means of its balancing planes. This rigging does not interfere in any way with the working of the armament and is arranged so that it can either be left permanently in place ready for immediate use, or may be quickly stowed away, the cables simply being hooked in heavy eye bolts and stretched taut to make them ready for use. This system enables the machine to be launched when a high sea would make it impossible to arise directly from the surface after being lowered overboard. The experiments carried out at San Diego in connection with the U. S. S. Pennsylvania demonstrated that the hydroaeroplane could be landed alongside and hoisted aboard in a wind of 10 knots and with a 4-knot tide running, the sea conditions being too rough for successful launching. Ability to get away from the ship at the crucial moment is regarded as being by far the most important point in the practical use of the aeroplane by the navy, since the wrecking or even the loss of the machine after the desired information had been obtained would be considered of minor importance. With the new launching apparatus, it is also possible for the ship to steam head into the wind at any desired speed, thus securing the necessary conditions for quick launching.

To thoroughly test this method, a platform was erected 150 feet from the shore of Lake Keuka and the necessary cables stretched from it to the water. The main cable was a ¾-inch steel rope made fast to a pile driven in the lake 250 feet distant and submerged so that the aeroplane could pass over it without damage. The machine employed was the regulation navy type of Curtiss hydroaeroplane, equipped with a 75-horse-power motor, fitted with the new Curtiss double control system and capable of carrying two persons at high speed. Its total weight is 1,200 pounds. The bottom of the pontoon under the hydroaeroplane carries a grooved runner, 1 inch wide by 1¾ inches deep, lined with sheet iron throughout its length and reinforced with iron bands at each end to form a durable bearing surface, while the outer ends of each lower plane were equipped with light irons, forming a bearing surface to engage the balancing wires strung on either side of the main supporting cable. The main cable was passed over a pair of shears 16 feet high, and fitted with a small platform from which the motor of the machine could be started. The grade was about 10 per cent. A simple releasing device was provided to start the machine on its downward slide, this consisting of a short length of rope fastened to the bow of the pontoon (also variously termed the float or hydroplane) and fitted with an eye through which passes a toggle pin connecting this short piece with a rope made fast to the legs of the shears. A sharp jerk on this rope pulled the toggle pin and released the machine, which quickly gathers headway under the combined force of gravity and the thrust of the propeller. During the trials, the machine was first floated on the lake and then hauled up on the cable. The prevailing wind was about 10 miles an hour, its direction slightly quartering against the line of flight, the trial apparatus naturally not possessing the mobility of a vessel at sea, as the latter could always be headed directly into the wind. In the first trials, two men held lines running to the outer ends of each wing to make certain that the machine would maintain its balance until sufficient headway was gained, but this assistance was found unnecessary. The machine rose easily from the cable after having traveled a distance of about 150 feet, attaining a speed of 30 miles an hour just before lifting. Numerous trials were carried out with unvarying success, demonstrating that the length of cable required is so short as to make the fitting of the new launching apparatus possible even on the smallest cruisers, as with the advantage of the head wind created by the speed of the vessel, the aeroplane could rise almost directly from the cable without having to take advantage of the full force of gravity by gliding down its entire length before beginning its flight. In the opinion of Captain Chambers, another year will see the hydroaeroplane developed to such an extent that each battleship of the American navy may have its own flying machine.

Combination Land and Water Type. Since bringing out the type of hydroaeroplane purchased by the navy, Curtiss has been experimenting with still further improvements, the new machine being equipped with wheels in addition to the large float. There are only two of these wheels, one at either side of the float about under the center of the lower main plane, the forward third wheel of the standard machine having been discarded. These wheels are pulled up out of the way by means of a hinged brace which runs from the wheel hubs to the front beam. The elevating rudder has been placed extremely low, at a level about midway between the lower main plane and the deck of the pontoon, while there is also a small auxiliary hydro-surface just forward of the pontoon and under its bow. A Curtiss standard eight-cylinder, V-type, 50-horse-power motor supplies the energy and drives the machine at a speed of 45 to 50 miles an hour over the water.

Curtiss Family Hydroaeroplane. As the result of his success in developing the hydroaeroplane for naval use, Mr. Curtiss has brought out a type designed for pleasure flying. Owing to the fact that it is intended to carry several passengers, this has been dubbed the "family hydro." It consists of a standard Curtiss biplane mounted directly on a single open boat of unusual size without any intermediate framing, so that the lower plane rests directly on top of the boat amidships. The passengers are seated in the bow of the boat just forward of the main lower plane, while the motor is mounted just underneath the upper plane, so as to allow the propeller sufficient clearance over the back of the boat and keep it out of the spray thrown up when the machine is skimming the surface rapidly. The side floats, or inflated tubes, employed on the previous machines to maintain them in lateral balance when skimming, are also a feature of the new passenger-carrying hydroaeroplane, which is said to handle as easily and safely as a fast motorboat, while having the advantage of the latter in that its lifting ability permits it to travel over rough water or to rise above it entirely. It is also capable of rising from and alighting upon the ground as well as on the water, as it is equipped with the folding two-wheel chassis just described in connection with another type of Curtiss hydroaeroplane.

Burgess Hydroaeroplane. It was only natural that W. S. Burgess, the well-known yacht designer, who some time ago forsook that field to take up the building of the Burgess-Wright biplanes, should also devote attention to the development of the hydroaeroplane. So far as the machine itself is concerned, it is of the usual Burgess-Wright two-propeller headless type, driven by a four-cylinder motor. The water supporting surface consists of two hydroaeroplanes 14 feet wide by 2 feet long and having a draft of 10 inches at their deepest point. They are designed to meet the water so as to create the minimum of head resistance or disturbance and are fastened comparatively close together under the center of the machine. They are of the single-step hydroplane type much used in racing motorboat design and are heavily trussed and reinforced to give them a high factor of safety. The first trials of the new machine showed it to be very speedy on the surface and with ample lifting power to raise the boats from the water. During one trial, Mrs. F. G. Macomber, Jr., was carried, she being the first woman to make a flight in a hydroaeroplane over the Atlantic. Flights were made under varying conditions ranging from a perfect calm to a 25-mile wind, and it was noticeable that the winds which would bother a skilled aviator over the uneven ground gave the novice no concern in the new hydroaeroplane over the water. In fact, the advantage is so great that doubtless most of the teaching henceforth at the Burgess school will take the form of over-water flights, as one of the greatest difficulties that both the manufacturer and the instructor have had to encounter is that of impressing upon the untrained novice, the importance of attempting to fly only in the most favorable weather.

Brown Hydroaeroplane. A departure from either of the foregoing types is found in the Brown hydroaeroplane which was built on the Chesapeake and has been successfully flown there. The aeroplane itself is of the original Henri Farman type, having ailerons attached to the outer rear trailing edges of both main planes, direction rudder at the rear, elevator of the single-plane type in front, and the propeller at the rear edge of the lower main plane, the aviator sitting just forward of the motor. The spread is 32 feet and the length 31 feet, the planes themselves being 3½ feet wide, while the distance between them is 4½ feet, this also representing the chord. The main planes are constructed in five sections and can be removed or replaced without the necessity of rebuilding an entirely new upper or lower main plane, as is usually the case. The camber of the curve is 3 inches and it is located one third of the distance back from the forward edge. Power is supplied by a 45-horse-power motor directly driving a 7-foot 6-inch propeller with a 5.9-foot pitch. The power plant, fuel, and water weigh about 450 pounds, and the hydroplanes and their braces 175 pounds, the complete weight being 1,000 pounds. There are three supporting hydroplanes with a total displacement of 27 cubic feet. They are designed with such an easy bow curve that they would skim the surface after the machine had not gone more than 50 feet, and would leave the water the moment the machine attained a good speed. The first hydroplanes employed were of sheet metal and of crude construction, but in spite of this drawback the machine showed itself capable of 40 to 50 miles an hour on the surface and 52 miles an hour in the air.

Detroit Flying Fish. A type of machine that is part hydroplane and part aeroplane is that recently placed on the market by a Detroit manufacturer, Fig. 62. It is aptly termed the "flying fish", as it is designed to do most of its travel by skimming over the water, seldom, if ever, rising more than 8 or 10 feet above the surface. It consists of a water-tight steel and aluminum tank, 2 feet deep, 5 feet 7 inches wide, and 7 feet 2 inches long. This tank, or pontoon, has a sloping bow, but is otherwise square. Mounted on this pontoon on steel tubing supports, about 6 feet high, are monoplane wings, or rather a single plane of 26 feet spread by 6 feet 6 inch depth. The supporting surface is of oil-treated canvas. The horizontal and vertical rudders are combined, the four-vaned plane of canvas being mounted at the end of a steel tube frame. This is the machine's aerial tail. Extending back of the hull and connected with the frame above it by tubing, is the marine tail. It consists of two steel arms and a wood transverse member a foot wide. On this flat board, 5 feet 7 inches in length by 1 foot wide, and ½ inch thick, the machine is expected to fly, or rather travel. When the speed is sufficient—

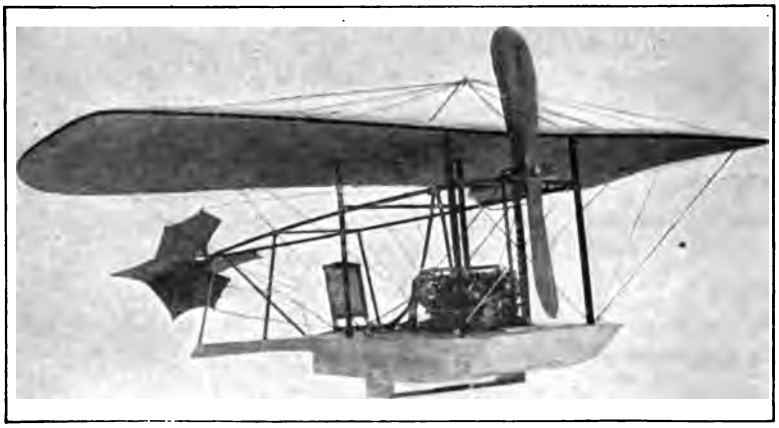


Fig. 62. Detroit Flying Fish

and the machine is expected to attain a rate of 65 to 70 miles an hour—the plane is designed to lift the hull out of water entirely, only the wood and steel tail touching at intervals to steady the flight. A powerful eight-cylinder, V-type, water-cooled motor drives a 6-foot two-bladed wood propeller through a chain. At the rear of the hull is placed a cane seat with a high back, the cockpit being directly in front of it. The control levers are mounted at either side. Complete, the machine weighs only 750 pounds. The first model made 65 miles an hour over the ice of Lake Michigan, scarcely touching the surface, although equipped with a much smaller motor. Though having every appearance of being a marine aeroplane, the machine is really more a hydroplane equipped with wings.

Transatlantic Hydroaeroplane. As the result of his long-continued and successful experiments with the hydroaeroplane, Glenn H. Curtiss who believes that the crossing of the Atlantic in one of these machines would be quite possible is ready to build a special aeroplane for the purpose, and Roger K. Wallace, chairman of the Royal Aero Club, London, is making efforts to raise £20,000 ($100,000) as a prize for the first America-to-England flight. H. N. Atwood, who made the first long-distance, cross-country flight in America—St. Louis to Boston—in 1911, has seriously proposed the undertaking, as has also James V. Martin, who is a master mariner, as well as a licensed aviation pilot. Mr. Martin gives the following data regarding the trip:

The two chief difficulties are the carrying of sufficient fuel for the 2,000-mile flight, and the question of navigation; the latter is more serious than it may at first appear as no great error would be necessary to divert the aeroplane from its course to such an extent as to largely increase the distance and risk a shortage of fuel. On this point, Prof. R. W. Willson, of Harvard, who has made a life study of the problems of nautical astronomy and aerial navigation, is authority for the following:

> Given an engine which can be absolutely relied on, a properly constructed aeroplane, and favorable weather, I see no reason why the transatlantic passage of less than 2,000 miles might not be successfully made. Assuming that the mechanical difficulties of keeping the aeroplane in motion can be successfully overcome, the navigating officer would first have to select the course to be followed, and by taking the ocean steamship "lane," the chances of loss in case of disaster would be materially lessened. The distance

from Newfoundland to England is the minimum. But the problem of navigating an aeroplane is a peculiar one. The path of a ship through the water is determined with considerable accuracy by the course and distance sailed as determined by the compass and the log, while astronomical observations are used to check this "dead reckoning" at stated intervals, unless prevented by clouds or fog. The aeroplane, on the contrary, may often be at a sufficient altitude to allow of an accurate determination of its position by observation, when a low-lying fog would cut off from a ship below the sight of the horizon necessary for the usual observation of the sun's altitude. The difficulty with the aeroplane is to keep account of its speed and its direction of motion, which is, of course, more dependent on the motion of the body of air in which it flies than the course of the ship is dependent on the ocean current or its leeway caused by the wind and sea. Since there is no treatise published on the subject, I would venture the following suggestions, which should naturally be thoroughly tested on the preliminary trials that should certainly precede any well-advised attempt to make the journey.

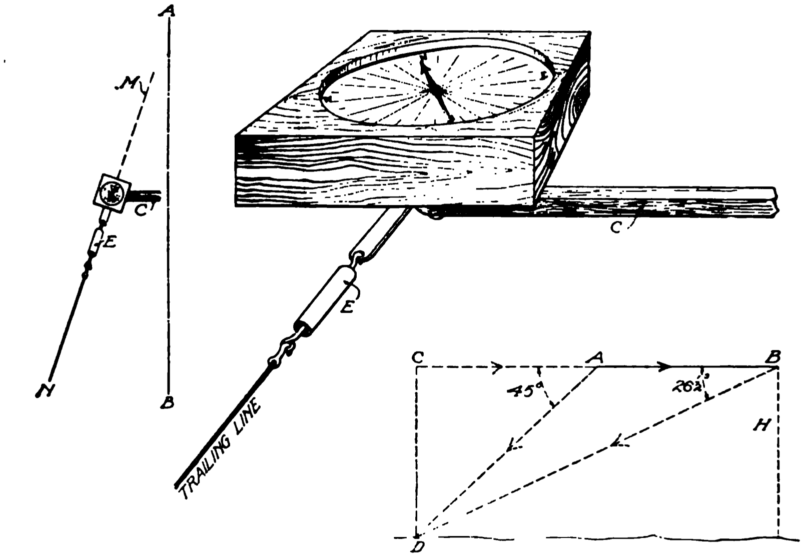


Fig. 63. Device for Determining Direction and Speed of an Aeroplane in Flight

In the first place, it should be definitely ascertained if, in good weather, the sea horizon is sufficiently defined for sextant observations at the height at which the passage would be made, remembering, of course, that the height could be decreased, if desired, merely for the purpose of making observations. On the occasions on which I have had an opportunity to observe the horizon at elevations of 2,000 to 5,000 feet, the uncertainty has been so great that I should estimate the error at 20 miles. Special refraction tables might be necessary at the height of a mile, though it is true that an uncertainty of 20 miles is of far less importance to the airman than to the seaman, and that his problem of a land fall is in some respects simpler. There should be no difficulty in making observations of the altitudes of the heavenly bodies if the development of the science of aviation makes it necessary. For determining the course and distance, it would be possible to learn something at any time when the aeroplane could be made to pass nearly over some well-marked point in the water beneath—how conspicuous such objects would have to be and how frequently they would be visible is uncertain. Patches and streaks of smooth water and perhaps other objects easily visible at a mile or two away, and sufficiently stationary to be used from a rapidly moving aeroplane for the observations of a four-point bearing, are not uncommon. By observing the time when the object *D*, Fig. 63, is directly beneath and again when it is left behind and depressed 45 degrees below the horizon, the distance traveled in the observed interval of time is equal to the height of the aeroplane, hence the speed may be determined while a compass bearing of the object taken at the same observation gives the course. Of course, all the methods of using two bearings and the elapsed time, which are useful at sea, may be modified in a similar way, the problem being the reverse of the nautical, the distance of the aeroplane from the water being used to find the speed, instead of the speed being used to find an unknown distance. Of course, it is necessary to know the height and for this purpose a reliable barometer should be carried, and it has been suggested that the often unreliable aneroid be checked by finding the dip of the horizon and then computing the height; this would be possible with a fair degree of accuracy at moderate heights and with a clear horizon by means of the navigator's prism. As proposed by Vaniman, the white caps can be employed as points of observation, while a steamer might also serve for this purpose, by making allowance for its speed. Doubtless, a method that would prove of great assistance involves no observations at all: This would be simply to obtain "positions" by wireless from passing steamers, and there are so many of the latter in the transatlantic lane that communication would always be easy. To ascertain direction and speed, a light line *N* with a float might be trailed in the water, and it is probable that only a very small float would be necessary, the large amount of line dragging furnishing the necessary friction. If the direction and force of the wind were constant at all levels from the aeroplane to the water's surface, or if conditions were such that all points of the line lay in the same plane, this plane would indicate pretty accurately the direction of flight, while conditions could be so arranged that the vertical angle at which the line left the aeroplane would give a measure of the speed. The latter might also be ascertained by the use of a small patent log at the end of a line, or by measuring the comparative tension of a spring inserted in the line where it left the aeroplane, as shown at *E*, Fig. 63. This line would be about 2 miles long and the aeroplane would be maintained at a height of 3,000 feet during the observation.

Probable Features of Design. The special difficulty in such an extended trip by aeroplane is that of sustaining the weight of oil and fuel necessary to keep the engines running during the period required for the aeroplane to travel from St. Johns, Newfoundland, to the coast of Ireland, a distance of approximately 1,800 miles. Opinion varies as to the type of machine best adapted to make such a trip, some believing that extreme speed should be the chief consideration in the design, since a speedy machine would lessen the time and require less fuel on that account. Others believe that a slow, large-surface machine would be more reliable, since it would carry more weight per horse-power than the fast machine. Doubtless, a design between these two extremes would lend itself best to the purpose, that is, a machine sufficiently powerful, relative to its area, to have a speed of 50 miles per hour in order to afford control in gusty winds. In attempting to increase the speed beyond this, the resistance increases so disproportionately that a very substantial increase in the size and weight of every part of the aeroplane would be necessary. On the other hand, a large surface machine may be relatively inefficient by reason of its slowness and very dangerous on account of its sluggishness in control. The machine proposed is a biplane with a span of 100 feet by a chord of 10 feet, or an aspect ratio of 10 to 1, and it could be propelled by five 50-horse-power revolving motors, geared down to two tractor screws. This would give it a speed of 50 miles an hour and a weight-carrying capacity of 7,500 pounds, 4,500 pounds of which would be useful load, an allowance that would provide for the carrying of two pilots, one engineer, and

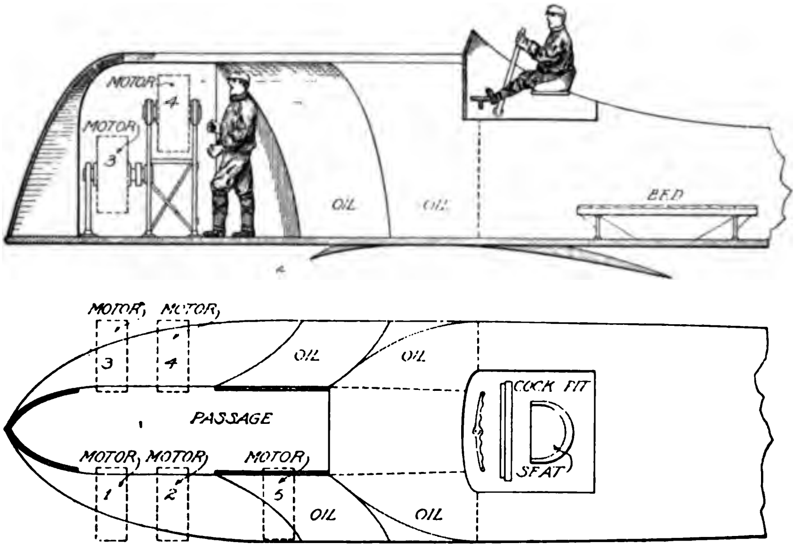
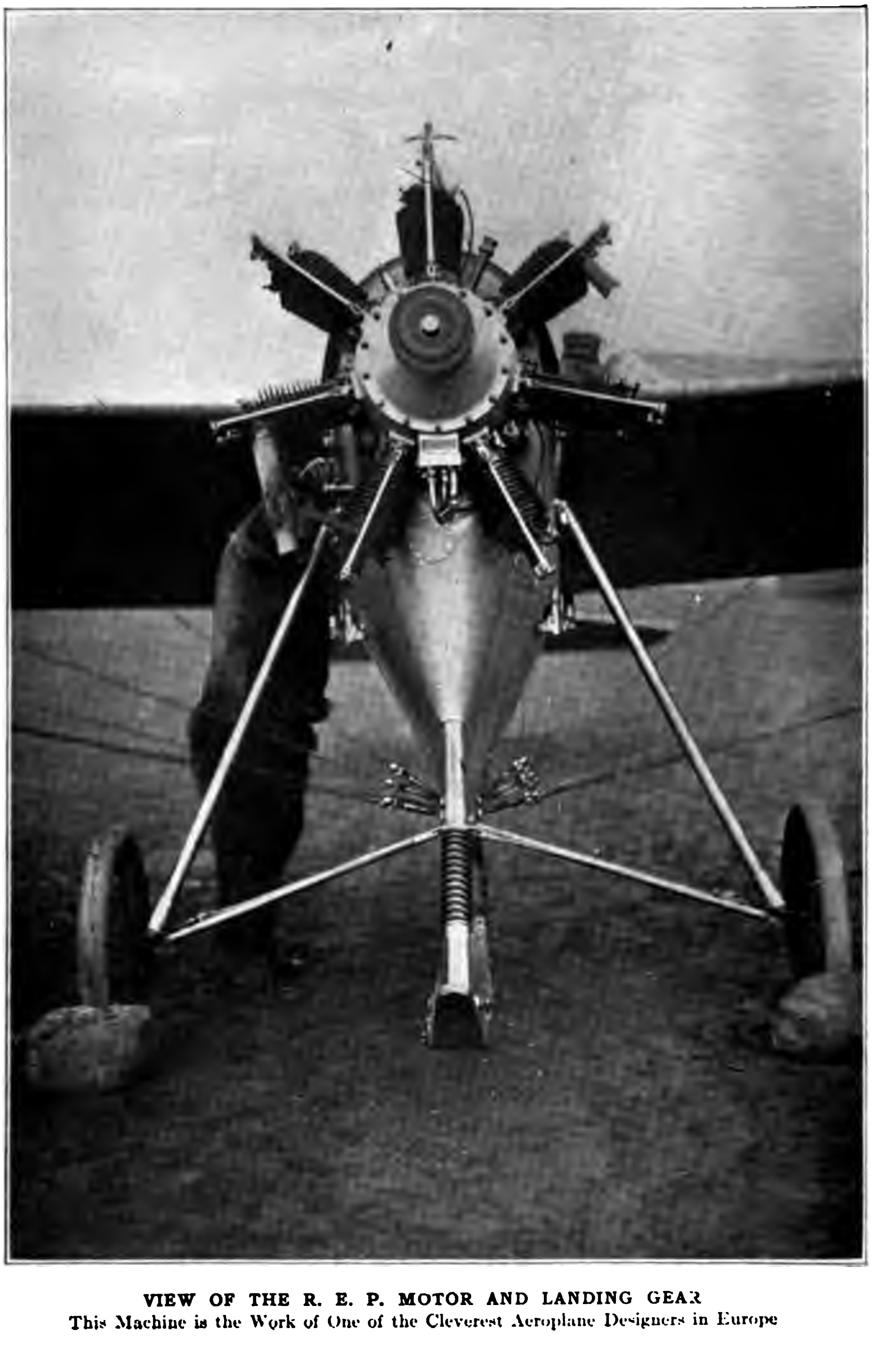


Fig. 64. Design of Transatlantic Hydroaeroplane

sufficient fuel and oil to drive the aeroplane at 50 miles per hour for 36 hours. Each of the engines would be fitted with a friction clutch, enabling it to be cut out at any time for inspection or adjustment. All five motors would be used to attain the necessary altitude and speed with full load, but as the fuel was consumed and the machine lightened, one after the other could be stopped, thus utilizing the fuel and oil to the greatest advantage. It might be possible to sustain the machine with only two of the motors running after most of the fuel and oil had been consumed.

The sketch, Fig. 64, shows a portion of the enclosed fuselage which is directly under the normal center of pressure. Sufficient fuel and oil could be stored here in tanks so arranged as to leave a 2-foot passage fore and aft from the cabin, just under the pilot's cockpit, to the engine room. The extreme width of the fuselage is 8 feet and it affords 6 feet clear headroom, the engines being placed on both sides of the enclosed central passage, making every one of them accessible. They would all be working in free air and would drive to a central transmission shaft, from which the tractor screws are driven by encased silent chains. The clutches would permit of throwing any one of the engines in or out of operation at will, so that the cleaning of the valves and spark plugs should be as simple a matter during the passage as at rest, though for that matter, experience has shown that a 36-hour run of a Gnome revolving motor that is clean and otherwise in good condition does not involve any particular need for inspection or adjustment. In a machine as large as that proposed, the passage fore and aft of the engine attendant would hardly be perceptible to the control of the operator. The resistance of such a machine should be quite low, since it has an enclosed streamline form throughout and since the single row of struts in the normal center of pressure of the planes greatly reduces the wire and strut resistance common to most biplanes. Though large, the controls are all of the balanced type, so there would be no difficulty in their handling by one man in gusty winds. Two boats would be employed as floats, the flat-bottom hydroplane principle being superfluous where the aeroplane has excess lifting capacity to raise them from the water. While light, these would be made so as to serve as lifeboats in case of emergency. If it became necessary to alight on the water in midocean, this could be accomplished in a comparatively smooth sea without great risk, and unless the seas were new and short, the aeroplane could take to the air again with little trouble.

It is practically certain that were this aeroplane to travel at its normal speed in the right direction for 30 hours at an altitude of about 5,000 feet, the passage of the Atlantic would be accomplished. A height of 5,000 feet would furnish an atmosphere comparatively free from the gusty surface winds and clear of all fog, so that, with a polaris instrument and a special azimuth table, it would not be necessary to depend on the compass for direction. This height would also give a greatly extended horizon (80-mile radius at 4,900 feet) so that there would hardly be a time on the passage over on the steamship route to Europe when some vessel would not be within the 160-mile range of vision. Noting the course followed by these vessels would also afford a check on the other methods of navigation employed. A glance at the pilot chart of the North Atlantic for July and August shows that there is a very dependable westerly movement of the upper air currents, so that it would be possible to rely upon a greatly increased speed of the aeroplane due solely to the wind.



VIEW OF THE R. E. P. MOTOR AND LANDING GEAR
This Machine is the Work of One of the Cleverest Aeroplane Designers in Europe

AERONAUTICAL MOTOR

Early Types. In the general acclaim that has greeted man's final conquest of the air, the chief contributing factor that has made it possible has to a great extent been overlooked. Power in sufficiently concentrated form appears to have been the only thing lacking for at least half a century past to have made possible for two or three generations what has been the reality of less than a decade. Not that a perfected light-weight power unit was sufficient in itself, as there are numerous principles governing flight that have been discovered only in recent years, but it was the one thing needed to lift a heavier-than-air machine from the ground and to keep it in the air. With its aid, it appears to be more than probable that the problem of the sustaining plane and the difficulties of equilibrium would have found a solution at a much earlier date. That at least one far-sighted investigator had realized the possibilities of the monoplane is shown by Henson's machine of 1843. Henson's steam engine was justly considered a marvel for its anticipated numerous features that are generally considered as the development of but very recent years in this form of prime mover.

But despite the great improvements it embodied and the fact that it could be operated continuously on but 20 gallons of water, its output was but 20 horse-power for a total weight of 600 pounds. Compare this low limit of 30 pounds per horse-power, of sixty years ago, with the 1.75 pounds per horse-power of the 140-horse-power Gnome motor and the advance that has been achieved will be appreciated. "Continuously" in this connection meant just what it does today—as long as the fuel holds out—and as coal is not only excessively heavy but likewise very inefficient for its weight when burned under a boiler, as compared with gasoline used directly in an internal combustion motor, it is evident that even with the great supporting power afforded by the 4,500 square feet of surface of the main planes, Henson's craft could not have carried sufficient coal to permit of much of a flight.

That extremely light weight was not the only desideratum is shown by Maxim's engine of 1892, which totaled only 600 pounds for an output of more than 360 horse-power, or actually less than 2 pounds per horse-power by an ample margin. The boiler weighed in the neighborhood of 1,800 pounds. The engines were compound and by an ingenious regulating device the high-pressure steam passed direct to the low-pressure cylinders when the boiler pressure exceeded 300 pounds per square inch, for which it was designed. This increased the output to 400 horse-power, the piston speed being 750 feet per minute, or more than a third less than what is now common practice with the internal combustion motor. While Maxim's engine, boiler plant, and equipment were extremely light for the power output, they had to work under the great disadvantage inseparable from the use of steam—that is, the low thermal efficiency of burning fuel under a boiler and the consequently increased amount that has to be carried. While ample sustaining area had been provided for this and similar purposes (4,500 square feet) the weight of the fuel necessary for a comparatively short flight would easily have exceeded that of the entire power plant. Apart from this the space *required* for the machinery was out of all proportion to the total space *available*, particularly as it would have been more or less essential to be able to get at the various parts of the plant during a flight.

In this case, the saving in weight was accomplished only at the expense of other disadvantages that would have rendered the final result immature had the machine been developed to a point where it could be actually employed in flight. But in looking back over the history of attempts at power-driven airships, it will be apparent that weight has been by far the greatest deterrent to success. For instance, Giffard's steam engine and boiler employed for driving a dirigible, in 1852, weighed 350 pounds, including coal and water, for an output of 3 horse-power. Dupuy De Lôme's dirigible of about twenty years later was a step backward in this respect, in that human power was employed. This meant a weight of close to 2,000 pounds per horse-power, while the maximum power would naturally be available only for short periods. The Tissandier electric power plant of 1882 had inherent limitations of so serious a nature where weight and restricted traveling radius were concerned that it can scarcely be considered as more than a freak. No one conversant with the drawbacks inseparable from electric power for this purpose would have made the attempt. The 1½-horse-power motor and its battery of primary cells weighed 500 pounds and the type employed (bichromate cells) was such that the power was available only for a very limited period. Despite these disadvantages the first dirigible to attain any measure of success was driven by electricity. This was the La France of 1884. equipped with an 8-horse-power motor, which has been referred to already in the earlier part of the work.

To Santos-Dumont doubtless belongs the credit of being the first to realize the great possibilities of the gasoline motor for aerial navigation. How he derived his inspiration from the motorcycle engine and the numerous attempts he made with dirigibles have already been dwelt upon. His first motor weighed between 15 and 20 pounds to the horse-power and, like everything he has been responsible for in connection with aeronautics, was designed on a very small scale, its total output not exceeding 4 horse-power. Although a pioneer in the field, Santos-Dumont has not been responsible for the subsequent development of the gasoline motor. At the time he took it up, the first stages of its evolution for automobile propulsion were being passed through and the difficulties encountered were so numerous and, in many instances, of such a puzzling nature, that it is easy to realize why attention was concentrated on perfecting it for a purpose that did not involve the further problems of successful flight. The history of the past twenty years shows that the development of the automobile motor was no small task in itself. With this fairly accomplished, the next step was principally one of refinement and adaptation.

GENERAL MOTOR REQUIREMENTS

To bring about its required refinement and adaptation in the aeronautic motor seems a comparatively simple matter, but that it has not proven so in fact will be realized upon reviewing the innumerable expedients that have been adopted by different builders to meet the conditions, and the many departures that these have involved from what may be termed automobile practice. In fact, in the few years devoted to its design, practically a new type of motor has been evolved. In order to obtain a clear understanding of how this has been brought about, it is first necessary to realize how exacting the requirements are and of just what they consist. Following this with a study of some of the more representative types that are now built for aeronautical use will reveal how the various principles laid down have been applied in each case. Before taking this up in detail, it may make matters a little clearer to briefly compare the automobile and the aeronautic motor.

Automobile vs. Aeronautical Motor. Generally speaking, the trend of the past few years, where the automobile motor is concerned, has been to develop a power unit of more uniform torque and of increased efficiency. The more general adoption of the six-cylinder motor and the increase in the length of the stroke, as compared with the bore, afford evidence of this. Little or no attention is now given to the question of weight saving, apart from any reduction that the use of integrally cast inlet manifolds, more direct water circulation, and similar efforts at cutting down the length of piping, may have been responsible for. Weights have reached a point where any substantial reduction could be brought about only by a more or less radical change in methods of construction, as well as the use of much more expensive materials. There would be little to warrant the increased cost of a much lighter motor, besides which it would involve the use of a higher speed to develop the same power with less weight. More important than any of these considerations is the fact that reliability suffers as the weight decreases.

Consequently, the tendency in the development of the automobile motor during the past few years has been mainly along the line of increased efficiency with practically no regard for the matter of weight, while the chief aim of the builder of aeronautical motors has been to get the latter down to the minimum. But that weight saving is not the sole governing factor in the design of a successful motor for flying is amply evidenced by the fact that the first aeroplane ever to make a flight—that of the Wright Brothers—was equipped with a comparatively heavy motor. Nor has this motor undergone any radical changes since it was first adopted several years ago. Like the Wright biplane of standard type, it is not only heavier but develops less power than many other experimenters have thought necessary for the purpose. But in it efficiency and reliability have been developed to a high degree and these vastly important qualities are very largely responsible for the numerous successful flights and for the high standing which the Wright machines enjoy in the field of aviation.

It did not take long, however, to reach a point in the development of the aeroplane where the speed of 40 miles an hour of which the Wright biplane was capable, was considered slow. The demand was accordingly for more and more power—the greater the driving force available, the smaller the sustaining surface needed, with a consequent reduction in the wind resistance. To meet this demand and still keep the weight down, every imaginable expedient has been resorted to by designers.

It has been said that the most important problem in the design of a light motor is the correct choice of type, but when what has already been accomplished in this field is passed in review, it will be found that there are aeronautical motors of every type ever tried on the automobile and many for which the latter was not responsible. Not all of them are successful, of course, but many of such widely differing types have attained such a measure of success that there is no telling what the advances of the next five years may be.

Fundamental Features of Design. *Short Stroke.* As an aeronautical motor of small bore and long stroke is much heavier in comparison to its power output than one in which these two dimensions are more nearly the same, design in this field has naturally gone back to automobile standards of several years ago when it was customary to build what are known as *square* motors, *i. e.*, those in which the bore and stroke are the same. In fact, it was nothing unusual for the bore to exceed the stroke. The advantages of a long stroke are increased efficiency and somewhat smoother running, the greater fuel economy and reduced vibration compensating for its inferior weight efficiency on the automobile. The majority of aeronautical motors are accordingly of the short stroke type, as the weight decreases very rapidly with a reduction in the length of the stroke. This was strikingly illustrated in the case of a large motor built for the Vanderbilt Cup race a few years ago. Its original dimensions were 7-inch bore by 7-inch stroke. In re-designing this motor, it was made 7 by 6 inches, the 1-inch reduction in the stroke being responsible for a saving of almost 200 pounds. The short-stroke motor has the further advantage of a low center of gravity.

Cost No Object. While compelled to reconcile numerous conflicting requirements, such as that of maximum reliability with the minimum weight, the designer of the aeronautical motor is not hampered so much by questions of cost. Consequently, many refinements of construction are available that could not be indulged in on the automobile motor. For instance, pistons are finished all over, inside and outside, and in some cases, the cylinders themselves are machined direct from a bar of solid steel at a cost many times greater than that of casting them of iron. Pistons in some cases are made of steel in order to attain the minimum thickness of wall, and every possible opportunity is taken advantage of to reduce weight, such as making the piston extremely short—even shorter than the stroke in some instances. Pressed steel is resorted to in the making of the connecting rods, or, where forgings are employed, they are simply riddled with holes to get rid of every ounce of metal.

Low Weight per Horse-Power. It must be borne in mind that, even at this early day, there are radically different standards among builders of aeroplanes. Some are constructed for purely sporting purposes. There are racing machines and touring machines, if the latter appellation be permissible. In the case of the former, the motor must develop a great amount of power for a comparatively short period. The fact that its construction is not particularly durable makes it possible to practically eliminate the question of any factor of safety in its parts. The latter are shaved down to the last fraction of an ounce and reliability is sacrificed in consequence, but before going into action the motor will be tuned up to its highest pitch, and if it will run long enough to cover a certain distance, that is all that is necessary.

Even aluminum has been employed for cylinders in rare instances, the bearing surface for the piston consisting of a thin cast-iron bushing forced into the aluminum casting. This has the great disadvantage of providing an aluminum explosion chamber and this metal loses its strength very rapidly as the temperature increases above a certain degree. It likewise involves the most expensive form of construction in that harder seats must also be employed for the valves, aluminum being entirely too soft for this purpose. Aluminum cylinder heads have also been employed with cast-iron or steel cylinders, but considerable trouble has been experienced with them owing to the great difference in the ratio of heat expansion between aluminum and cast iron or steel. Consequently, aluminum is no longer employed for such important parts.*

In addition to drilling the connecting rods, they are usually made very much shorter than in automobile practice, this being as low as 1.5 to 1.75 times the length of the stroke in motors of a type which are inherently well balanced by reason of their design, such as the six-cylinder vertical or the three-cylinder radial. It will seldom be found to exceed 2 to 2.25 times the stroke, the evil of increased friction of the piston against the cylinder walls due to the greater angularity of the short connecting rod being partly compensated for by offsetting the crank shaft with respect to the cylinder center. By this means, the pressure between the piston and cylinder wall are practically equalized on the compression and power strokes. The crank shaft, cam shaft, and even the valve lifters are drilled to reduce weight, the passages thus made eliminating every bit of unnecessary material, and affording convenient means of lubrication.

Automatically-Operated Inlet Valves. In this connection, a further reversion to what is now obsolete in the automobile motor is to be considered. This is the employment of automatically-operated inlet valves. In view of the fact that the aeronautical motor is seldom called upon in service, to vary its speed much, the high degree of flexibility to which the automobile motor has been developed is of no particular advantage and the shortcomings of the automatic type of valve are not a serious drawback. Probably no better instance of the employment of the automatic valve could be mentioned than the Gnome revolving-cylinder motors.

As is the case with most other important parts of the aeronautic motor, experience with the automobile has been drawn upon

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*In general, however, aluminum or aluminum alloys have been used wherever it is possible to substitute these alloys for the heavier metals, such as iron or steel. The attempt to use them for casting the cylinders is not new, but aluminum itself is not suitable and difficulty has been found in making a proper alloy. But within the past year (1911) magnalium has been successfully employed for this purpose. This consists of pure aluminum with a slight percentage of the metal magnesium and the resulting alloy is not only denser but is about 12½ per cent lighter than No. 12 aluminum, which consists of 93 per cent aluminum and 7 per cent copper, and has a specific gravity of 2.82. Magnalium accordingly weighs about one third as much as cast iron, while its thermal conductivity is seven to eight times greater, which greatly facilitates the cooling, especially of air-cooled engines. Unlike other aluminum alloys that have been employed for cylinders, tests have demonstrated that it gives better service than iron under the same conditions, as the bore of a magnalium cylinder takes on a mirror polish after only a few hours running, while the surface becomes very hard, as has been shown by the piston and rings of a poorly-bored cylinder becoming scored instead of the cylinder walls, as would usually be the case. Owing to its greater strength as well as reduced weight, it is also being employed for crank cases and other motor parts. The expense, however, would be prohibitive for anything but an aeronautical motor.

in the placing of the valves. The high-speed automobile motor has shown that the most advantageous valve arrangements are those in which the valves are in the head, and the so-called De Dion arrangement in which the valves are in line with each other. The reasons for this will be obvious when it is borne in mind that power is obtainable only with high speed where the valves are very liberally proportioned with regard to the cylinder bore. The combined inlet and exhaust valve, as developed on the Franklin air-cooled motor, has also been successfully applied to the aeronautic motor. Placing the valves in the head makes possible a very simple form of explosion chamber with a minimum of wall surface, with consequently increased thermal efficiency as compared with a form of cylinder head involving the use of valve pockets. The absence of the latter prevents the retention of spent gases, which gives increased power and fuel efficiency by reducing the tendency to premature ignition and by the use of higher compression pressures, which mean higher temperatures. The importance of this is obvious in view of the close weight limitations, and it is accordingly customary to employ higher compression pressures and speeds than in the automobile motor. Considerable interest at present attaches to the development of motors with rotary valves, or sliding sleeves and ports instead of valves, as in the Silent-Knight motor. So far little definite progress appears to have been made with the adaptation of this type of motor to the aeroplane, but numerous attempts are being made to evolve a practical form of rotary valve. The Knight motor itself does not offer any advantages of either simplicity or reduced weight so that the solution does not lie in that direction. An interesting development where the valves are concerned is found in the Adams-Farwell rotary motor in which the fuel is injected directly into the cylinder so that only one valve is necessary for each cylinder, and this can accordingly be made of very liberal diameter.

Standard Forms. The foregoing will suffice to give some idea of the difference in design and requirements between the aeronautic and the automobile motor, as well as those features of the latter which have been found advantageous in the new field. But so far, merely the parts themselves have been touched upon. It is in their assembly that the greatest divergence between the two standards is found. A glance over the numerous types that are sufficiently successful to remove them from the class of freaks, or mere proposed forms of construction that have not yet got beyond the paper stage, reveals the fact that every form of automobile motor that has ever been devised, has its counterpart among the newcomers, besides many which were never thought of in that connection. At one end of the list, there is the single-cylinder, air-cooled, motorcycle engine with which Santos-Dumont made his first attempts at dirigible propulsion, and at the other the highly refined and extremely ingenious fourteen-cylinder revolving Gnome motor, and the sixteen-cylinder **V**-shaped Antoinette. Between these two there is every form imaginable, even the two-cylinder horizontal opposed—that hybrid type of purely American origin and development, which foreign designers have always affected to despise, now being built by some French makers.

V-Form. The **V**-form, or 90-degree arrangement in which each pair of cylinders acts upon the same crank pin is very largely employed, both the Wright Brothers and Curtiss using this type in their more powerful machines. This arrangement permits of using a crank shaft of practically the same dimensions as a four-cylinder motor of the same size and is accordingly a great saving of weight. It also makes it possible to actuate all the valves from a single cam shaft, placed in the point of the **V**. From this arrangement, developments have led to the placing of three cylinders round a common crank case in the same vertical plane, also seven cylinders, three in one plane and four in another, as in the Esnault-Pelterie motor. Motors of this and similar arrangement are popularly referred to as "fan" and "star" types, and as all the cylinders act on the same crank pin, and the valve gear is reduced to its very simplest form, the saving in the weight of the crank shaft and crank case thus effected may readily be appreciated. When first attempted such motors did not give much promise of being practical, but as they have proved such a success in actual use, they are now one of the most popular forms of light-weight motors. Their chief disadvantage lies in the amount of space occupied in the direction across the cylinders, making them awkward for use in a dirigible for which a specially designed basket or car of greater weight is necessary.

Revolving Cylinder. Of even less promise at the outset was the revolving-cylinder motor, in spite of the fact that this type had been developed to a high degree of reliability and efficiency in the Adams-Farwell car. In addition to the other difficulties of design, the gyroscopic effect of the revolving mass had to be taken into consideration. It is well known that a large flywheel, revolving rapidly, forcibly resists any attempt to change its plane of rotation, advantage having been taken of this principle to balance a mono-rail car on its single support, and to keep torpedo boats steady in a seaway. While the revolving-cylinder motor dispenses with a flywheel, its revolving mass acts in the same rôle and plays the part of a gyroscope. Placing the latter horizontally would tend to increase the stability of an aeroplane without appreciably affecting its steering, but it was thought that where run in a vertical plane, as is necessary in order to obtain direct driving of the propeller, it would interfere with rounding curves of short radius. In the case of the Bleriot monoplanes with a revolving-cylinder Gnome motor right up forward, this does not appear to have been the case.

The chief advantage of this form of motor is its ability to dispense with a flywheel of any kind and its highly efficient air cooling. The latter has proved effective even with motors of comparatively large size, using an initial compression as high as 75 pounds to the square inch. One thing that the aeronautic engine designer does not have to contend with is dust and grit, so that in some instances all provisions for excluding it have been omitted.

Correspondingly greater difficulties are found, however, in the very important essential of lubrication and in the disposition of the piping. Special means have to be resorted to in order to insure the oiling of every moving part, particularly where centrifugal force enters to complicate the problem, as in the revolving cylinder motor. The lubricating system employed on the most representative type of the latter—the Gnome—is very effective but likewise very wasteful, as the oil is merely pumped through the motor and out into the air. But even in the **V**- and fan-shaped motors, where the cylinders stand directly over a crank case, as on an automobile motor, splash lubrication can not be employed. The last cylinders in the direction of the motor's rotation would receive very little oil. Fewer difficulties are encountered with the lubrication of motors having their cylinders placed horizontally and provided with a vertical crank shaft, as in the case of the Farcot and Clement engines.

The problem of properly arranging the piping is one that has led to numerous ingenious expedients, such as the employment of independent feed pumps for each cylinder on the eight- and sixteen-cylinder Antoinette, instead of a carbureter and the usual complicated inlet manifold. The latter is even more cleverly dispensed with in the case of the Gnome revolving motor, in which the mixture of air and gas is led through the hollow stationary crank shaft, the different cylinders receiving their supply through automatic inlet valves placed in the heads of the pistons. Where the flying machine is concerned the question of piping has one redeeming feature in that it is permissible to exhaust directly into the air. No one but the pilot of the aeroplane is inconvenienced by this, but the roar is such that it is quite likely a muffler will be a feature of the aeroplane motor before very long. On the dirigible, it would naturally be very dangerous to permit the escape of the exhaust anywhere near the gas bag, and accordingly a muffler is not only employed, but in some cases both the exhaust and the muffler are water cooled to make certain of reducing the temperature of the exhaust to a safe limit.

Flywheel. One other advantage enjoyed by the aeronautic motor is the fact that it is possible in most instances either to dispense with the use of a flywheel altogether, or reduce its weight to an almost negligible factor. But just as early investigators in the automobile field did not appreciate the full value of a heavy flywheel, so some designers of aeronautic motors do not consider it as important as it really is, in view of the particular types of motors they employ. Naturally, the conditions are quite different, as the propeller, though very light, is of large diameter and where directly attached to the crank shaft, does away with the necessity for a flywheel. In reviewing the large number of aeronautic motors now on the market, which is done more in detail a little further along, all shades of opinion will be found represented where this ordinarily important essential is concerned. They range from the conventional cast-iron flywheel of automobile type found on the Wright motor to a perforated-steel stamping, as in the Vivinus, or none at all, this being the case even on two-cylinder, horizontal-opposed motors in which the impulses are very intermittent. Examples of this are found in the Darracq and the Deuthil-Chalmers, both of French make.

Number of Cylinders and Weight Saving. Mention has already been made of the fact that there is a great diversity of opinion among aeroplane motor designers regarding the number of cylinders. As the weight of an engine may be roughly divided into cylinders and pistons on one hand, and the crank case and crank shaft on the other, assuming the conventional type it will be evident that the number of cylinders has a direct bearing on a most important factor—that of weight. In the numerous "spider" types of motors—if they may be so called—those in which the cylinders radiate from a very much abbreviated crank case with a correspondingly reduced crank shaft, this proportion naturally does not hold good. There are, of course, many other factors to be considered in the selection of the proper number of cylinders and it will be apparent from a study of the examples illustrated and described that designers have become very largely divided into three general classes: Those favoring what may be termed the conventional type, through its familiarity on the automobile—that is, the vertical or V-arrangement of cylinders; those who favor variations of the radial arrangement; and those who pin their faith to the revolving motor, this really being a subdivision of the second class.

Assuming a constant r. p. m. rate, both the power output and the weight of a cylinder increase as the product of D^2L, D denoting the diameter of cylinder, L the length of stroke; but if a constant piston speed be assumed, such as the standard of 1,000 feet per minute adopted by the Association of Licensed Automobile Manufacturers, on which to base motor ratings, the power, only, increases as the square, while the weight still increases as the product of D^2L. For moderate powers, the actual weight of the cylinders themselves appears to be but little influenced by their number, but it will be obvious that with any substantial increase in power, the weight of a smaller number of comparatively large cylinders should be less owing to the difficulty of reducing the thickness of the cylinders in proportion to their reduced dimensions. Experience has also shown that an engine with a few large cylinders has a very much higher factor of reliability and is easier to maintain, than one with a large number of small cylinders. While exceedingly fast time has been made over short stretches by an eight-cylinder V-type automobile motor—the 200-horse-power Benz—the fastest time in road races over long distances has thus far always been to the credit of the four- or six-cylinder motor of conventional design.

In addition to almost eliminating the crank case, the small multi-cylinder radial type also dispenses with the flywheel. This last, of course, is equally true of any motor employing six or more cylinders, as the multi-cylinder motor has the great advantage of producing a much more even turning moment. The drive is not continuous in a four-cylinder motor and, theoretically, it will not run at all without a flywheel. However, as the motor is directly connected to the propeller in the majority of instances, the latter is frequently found an efficient substitute. The more uniform torque of the motor with the greater number of cylinders is an added advantage in not imposing such severe stresses on connections as is the case where a smaller number of power units is employed. But the question of reliability enters here again, and as there is always the possibility of one or more cylinders of the multi-cylinder motor ceasing to fire, the reversal of stresses is then quite as great as with fewer cylinders.

Coming back to the question of weight saving—and at the present time it is evident that this is the chief controlling factor—let us see what are the steps leading up to the extremely light-weight modern motor. With the conventional arrangement, *i. e.*, cylinders vertically in a row, the weight of the crank case and crank shaft naturally increase in proportion to the cylinder capacity. By placing two rows of cylinders on the same crank case, as in the usual V-arrangement, the size of the crank case and crank shaft are but slightly larger than for the single row and the weight is cut almost in half. With eight cylinders at 90 degrees, the impulses are evenly spaced throughout the revolution, each pair of opposite cylinders being connected to one crank. But both impulse and mechanical balance are obtainable with as small a number as two cylinders, where the latter are arranged in what is known as the horizontal-opposed motor. The cylinders are slightly offset on opposite sides of a very short crank case and they act upon oppositely-disposed cranks—in other words, a two-throw crank shaft with the pins placed 180 degrees apart. This gives a very smooth running motor where two or any multiple of two cylinders are employed.

The advantages of this type are mentioned at greater length here as they have only recently received that measure of appreciation which they deserve, as will be noted later in the successful motors of this type that are now in use. While the crank case and crank shaft of the horizontal-opposed motor increase in proportion to the increase in cylinder capacity, as compared with the diagonal or "spider" motor, the impulses are more even and the balance better than in the latter when using less than four cylinders.

In order to give the student a clearer idea of the manner in which the crank case and crank shaft are affected by the arrangement of the cylinders, with a corresponding reduction in the weight, the accompanying illustrations may be referred to. In these sketches the details have been intentionally omitted to prevent confusion; in actual practice, the space between the open ends of the cylinders on the crank case would be very much less than is here indicated. Fig. 1 is the conventional four-cylinder vertical motor as employed on the automobile. In this case the crank case must necessarily be slightly longer than that of the combined length of all the cylinders. The first step away from this is the V or 90-degree arrangement, as shown by Fig. 2, which illustrates the elevation and the plan. A similarly great reduction in the size of the crank case is effected by the horizontal-opposed arrangement, Fig. 3. Either the diagonal or opposed arrangement lends itself readily to two, four, six, eight, ten, or more cylinders, motors of

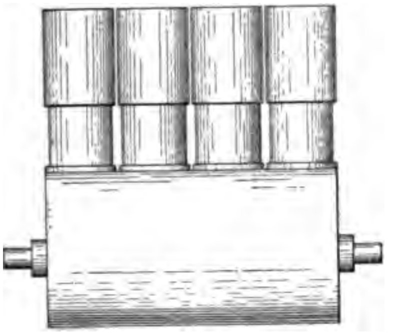


Fig. 1. Four-Cylinder Vertical Type

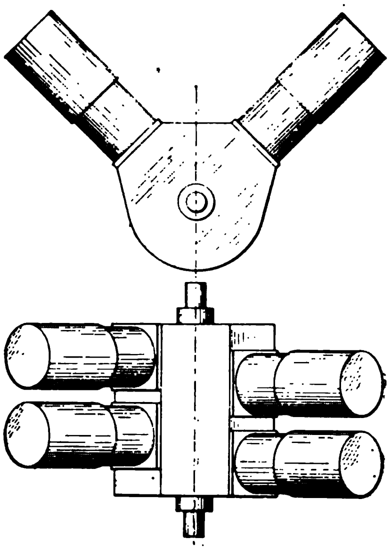


Fig. 2. V-Type of 2 to 16 Cylinders

the diagonal type being built with as many as sixteen cylinders. The first step away from this type is what has previously been referred to as the fan or radial arrangement as shown by Fig. 4, also as carried further by the addition of an extra pair of cylinders, as in Fig. 5.

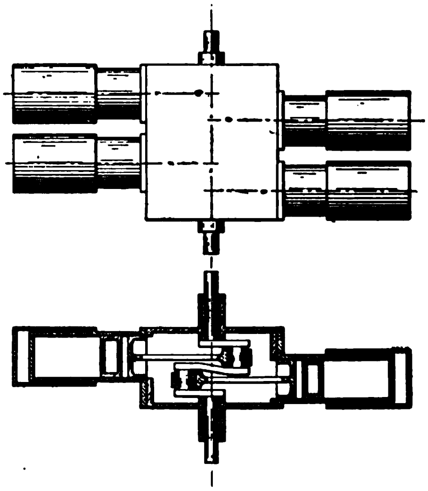


Fig. 3. Horizontal-Opposed Type

This type naturally does not lend itself as well to water cooling as the first, second, and third arrangements illustrated, owing to the necessity of providing an independent jacket for every cylinder with the attendant complication in the piping. But for air cooling this type is ideal, as the cylinders are so spaced that each one receives an equal amount of air and none can radiate its heat directly to any of the others. The question of water versus air cooling is naturally again to the fore in this field, but under very different conditions for the latter than where the automobile is concerned. Whether directly connected to the propeller or used to drive the latter through a transmission system, the motor itself is always completely exposed to the air and is cooled by a current averaging 40 to 60 miles an hour, or even greater. There would appear to be no possibility of ever working an air-cooled motor so hard, even on a warm summer day,

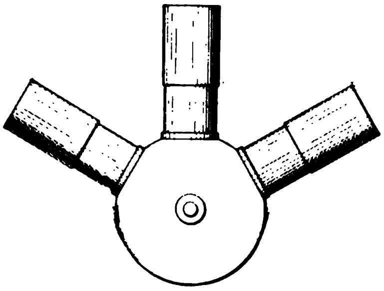


Fig. 4. Three-Cylinder Fan Type

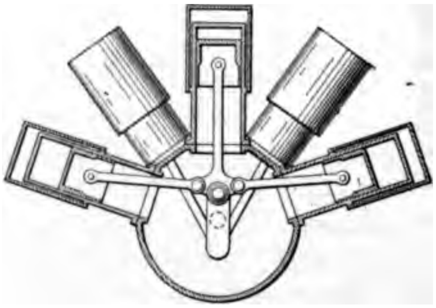


Fig. 5. Five-Cylinder Fan Type

as to cause it to be any less reliable on the score of danger of overheating, where the conditions are so favorable. On the other hand, with a multi-cylinder motor of the radial type, the complications of the piping system and connections would be a source of danger in themselves. For numerous reasons, none of which appears to have the slightest bearing on its efficiency or reliability as judged from a purely engineering viewpoint, the air-cooled motor has a rather limited use in the automobile field.

Where the aeroplane is concerned, however, weight saving is of vital importance and space is also a factor which must be closely considered. The designer of aeroplane motors is neither hampered by restriction of style nor by a commercial demand. He does not have to cater to a buying public that has to a great extent conventionalized automobile design, by refusing to aid the manufacturer whose designs in any way departed from the conventional. It accordingly seems quite probable that the question of air cooling will be worked out on the aeroplane motor from a purely engineering viewpoint. Even where the cylinders of a radial type of motor, such as that shown by Fig. 5, are placed so close together there should be no difficulty in properly cooling them.

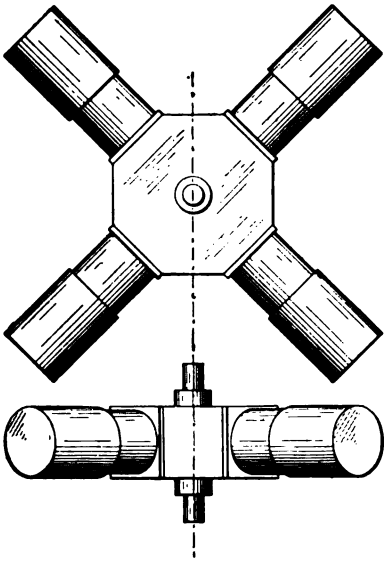


Fig. 6. Four-Cylinder Star Type

A modification of Fig. 4 is illustrated in Fig. 6, which shows a four-cylinder radial motor. In practice, however, four is not a good number for this type, as the impulses can not be evenly divided, which accounts for the general use of an odd number of cylinders in a radial arrangement. Such a motor can be satisfactorily balanced where the cylinders are evenly spaced about the circumference of the crank case, as all the connecting rods are attached to a common crank pin, and, therefore, form one revolving mass, which can be balanced by a suitable balance weight. But as the number of cylinders increases, the difficulty arises of attaching all the big ends of the connecting rod to one crank pin, without making the ends of the connecting rods unusually narrow or the pin itself over long. This is obviated by the arrangement shown in Fig. 118, one connecting rod, the upper one in the sketch, being formed with a disk to which the others are attached by means of bosses, or short pins.

In balance, this engine is naturally superior to either of the arrangements shown in Figs. 4 and 5. In the case of Fig. 4, the placing of all the cylinders on top of the crank case makes it impossible to divide the impulses evenly, and this motor has to be built with heavy inside flywheels, similar to a motorcycle engine. With this addition, such a motor runs well, but it is a question whether the advantage of greater accessibility gained by placing the cylinders in this position, is not more than offset by the extra weight of the flywheels that could be saved by disposing the cylinders equidistant around the crank case, so that the impulses would come 120 degrees apart.

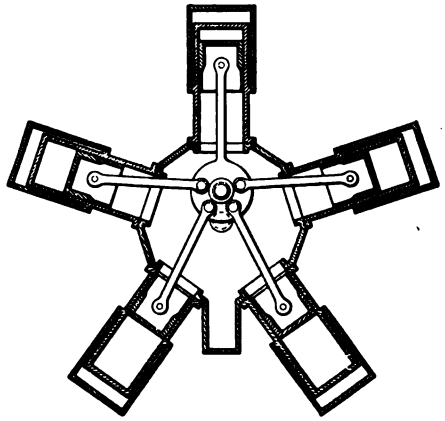


Fig. 7. Five-Cylinder Radial or Star Type

Fig. 5 is really a five-cylinder radial engine with the two cylinders shown below in Fig. 7 placed on top of the crank case. In this case, three of the pistons actuate one crank and the remaining two another, the cranks themselves being opposed or 180 degrees apart. The division of the impulses is the same as in the complete radial engine, Fig. 7, and the balancing almost as good, but the crank shaft has to be of a larger diameter owing to its weaker form, and as both it and the crank case are longer, there will be an increase in the weight. Take Fig. 7 and assume that its crank shaft is held stationary, and we have the usual revolving type of radial motor which has proven so successful in service. It does not require any great amount of study to show that whether the cylinders revolve or remain stationary, the total weight of the motor will be the same, assuming the accessories and fittings in each case to be similar. This being the case, the only manner in which the revolving cylinders can be of any advantage is either to make the crank case and the cylinders themselves lighter, or to obtain more power for the same sized cylinder when revolved.

The chief advantages of the revolving motor are that it dispenses with a flywheel and makes air cooling more positive. Under the conditions obtaining on an aeroplane soaring at any considerable height, it may be questioned whether this is not really too much so, the great reduction in the temperature of the motor very unfavorably affecting its efficiency and unduly increasing its fuel consumption. That this is quite likely to be the case will be apparent from the fact that in a revolving motor in which the ends of the cylinders are 15 inches from the crank shaft, the former will be moving through the air at 95 miles an hour when the motor is running at 1,200 r. p. m. In practice, the power obtained per cubic inch of cylinder capacity from the Gnome motor is small, and it seems quite probable that the same power could be obtained by employing fixed cylinders of smaller dimensions. That it is extremely light for its size will be seen from its weight of but 0.35 pound per cubic inch of cylinder capacity, but this is undoubtedly due to the high-grade materials used and the methods of machining employed in its construction.

Another point of importance in the comparison of these various arrangements that is quite as vital as that of weight, or will be as soon as durability in an aeroplane motor is given proper consideration, is their effect on the bearings. By grouping the cylinders the crank case is shortened but the work put on the bearings is increased, without, in most cases, any proportionate increase in the amount of bearing surface. For instance, in the diagonal or V-type, each main bearing has to take the load of two cylinders, instead of one. This is aggravated still further by placing three cylinders on top of the crank case and in the radial type matters are still worse, though in the latter, various expedients to overcome this, such as that illustrated by Fig. 7, are adopted.

The difficulty of lubricating the radial type of engine has already been mentioned and need not be repeated here. Just how each maker has solved this extremely important part of the problem of his design, will be referred to in connection with the descriptions of a number of prominent American and European aeronautical motors that follow.

AMERICAN MOTOR TYPES

Wright. As the Wright motor was the first to leave the ground in a man-controlled aeroplane, it is natural that it should be given prominence in this connection. When the Wright Brothers attacked the problem of using power for their flights they searched the market for a suitable motor but were unable to find anything that met their requirements. It will be recalled that the automobile motor was not a very highly developed power unit in 1902. They were accordingly compelled to develop a design by study and experiment, as in the case of the aeroplane and the propellers. The result is an exceedingly simple and efficient motor of the four-cycle type which at first glance resembles the present-day automobile motor of light cars, particularly since the practice of making an oil tank an integral part of the crank case has come into vogue. The Wright motor is of the four-cycle type, the cylinders being cast independently of gray iron, while the crank case, of unusual depth, is of aluminum alloy, as are also the water jackets of the cylinders. The exhaust valves are in cages opening directly to the air and are operated by means of rocker arms, as they are placed in the head, alongside of the automatic inlet valves. The crank shaft is of nickel steel and in accordance with the practice that obtained in the automobile field seven or eight years ago, it is *whittled* out of a solid block, the cam shaft also being machined from the bar in the same manner. Oil is carried in a special tank forming the bottom of the 1-piece crank-case casting, lubrication being insured by a small gear type of pump driven from the cam shaft. A second small gear pump driven in the same manner and located beside the oil pump, shown in the illustration of the right side of the motor, Fig. 8, is for the purpose of supplying the fuel to the engine, a carbureter being dispensed with in view of the extreme variations of altitude under which the motor must operate. As will be apparent from the photo, this pump delivers the gasoline direct to a mixing chamber located at an elbow of the intake manifold, the end of which is open to the air. An injector controls the amount of gasoline supplied to each cylinder in direct proportion to the speed of the engine. By comparison with the highly developed type of carbureter now employed on the automobile, this device appears to be a reversion to the old stationary engine type of mixer, but it must be borne in mind that an aeroplane motor constantly operates at its normal or even maximum output, so that provision which would be totally unsuited to automobile use in view of the demand for the greatest possible range of speed and power output, is undoubtedly far more reliable under such ideal conditions of operation.

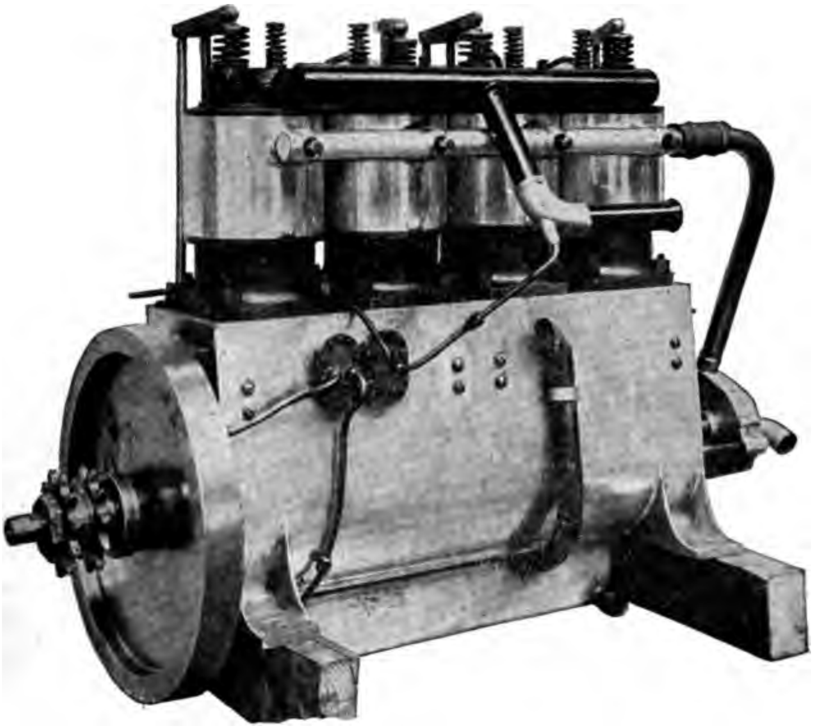


Fig. 8. Right Side of Wright Four-Cylinder Aeronautical Motor

Ignition is provided by a "Mea" high-tension magneto driven by a two to one gear on the end of the cam shaft but outside of the crank case, the magneto being set on a bed cast integral with the latter. In this type of magneto, the entire field magnet is arranged to oscillate about the armature, so that regardless of the position of "advance" or "retard" for which the spark control is set, the spark always occurs at what is known as the "peak of the curve," *i. e.*, the point of greatest current flux, giving a spark of the maximum value for ignition purposes. The cooling water is circulated by means of a centrifugal pump attached directly to the end of the crank shaft, as shown by the view of the left side of the motor, Fig. 9, which also illustrates the magneto and its drive. The radiator consists of a small group of flat, vertical, copper tubes, several feet in height, and with small aluminum headers at each end. Unlike many designers of aeronautic motors, the Wright Brothers have not attempted to reduce weight at the expense of safety, as will be very apparent from the liberal flywheel provided. Where not more than four cylinders are employed, there is no single feature that adds so greatly to the reliability of a motor and the uniform delivery of its power output, as a flywheel of ample weight. This essential is of web pattern and is of cast iron, instead of the usual spoked wheel commonly employed. The cylinder dimensions are 4⅜-inch bore

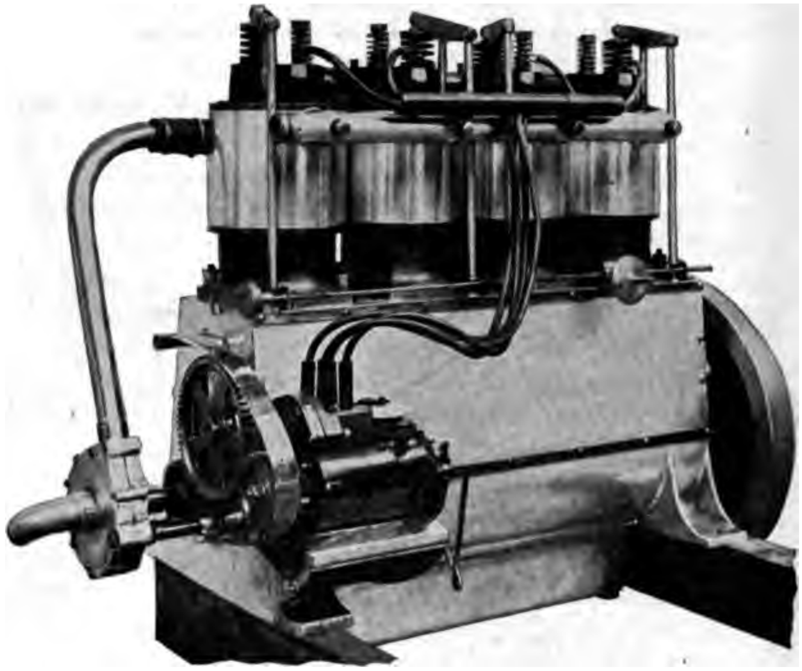


Fig. 9. Left Side of Wright Four-Cylinder Motor Showing Magneto and Its Drive

by 4-inch stroke, the power output being 30 to 35 horse-power at about 1,200 r. p. m. The total weight, not including the radiator or water supply, is 180 pounds, or 5½ to 6 pounds per horse-power, which is very high as compared with the weights of the majority of aeronautic motors. The power is transmitted to the propellers through the two sprockets shown on the crank shaft at the flywheel end, and nickel steel roller chains, one of the latter being crossed to reverse the motion of its screw. The propeller shafts are of chrome nickel steel and are carried on annular ball-bearings. The high degree of reliability shown by the Wright motor in service affords a striking illustration of the fact that extremely light weight is far from being the chief thing to be desired in an aeroplane motor. For the "baby" Wright machine and the "racer," an eight-cylinder, V-type motor, Fig. 10, which is characterized throughout by the same features of design, is employed. This is rated at 60 horse-power, and is designed to drive the propellers at a much higher rate of speed than in the standard machine in which they turn at 400 r. p. m.

Fig. 10. Complete Power Plant and Transmission of Wright "Baby" Biplane

Curtiss. On the early Curtiss aeroplanes, a four-cylinder, vertical, four-cycle, air-cooled motor, which was practically the same in most respects as the standard automobile type, was employed.

This developed about 25 horse-power. It soon gave way, however, to an eight-cylinder, V-type motor of the same general design rated at 50 horse-power, and it has been with this motor that Curtiss has made all of his flights of note. The new Curtiss racer is provided with a water-cooled motor, Fig. 11, something which serves to accentuate the difference in the conditions between land and air travel. It would appear that in view of the high wind blowing on the motor and the low temperature of the air blast, that air cooling would present no difficulties whatever. As already mentioned, however, an aeroplane motor operates constantly under full-load conditions, and the rear cylinders of a longitudinally-arranged motor are apt to become overheated despite the constant supply of cold air blowing on them. This, in addition to involving the risk of stopping the motor without warning, also cuts down the power of these cylinders due to the rarefaction of the fuel mixture at a high temperature, makes lubrication difficult, and greatly increases the consumption of lubricating oil. Tabuteau's 8-hour flight in France with a Renault air-cooled motor shows the efficiency of air-blast cooling.

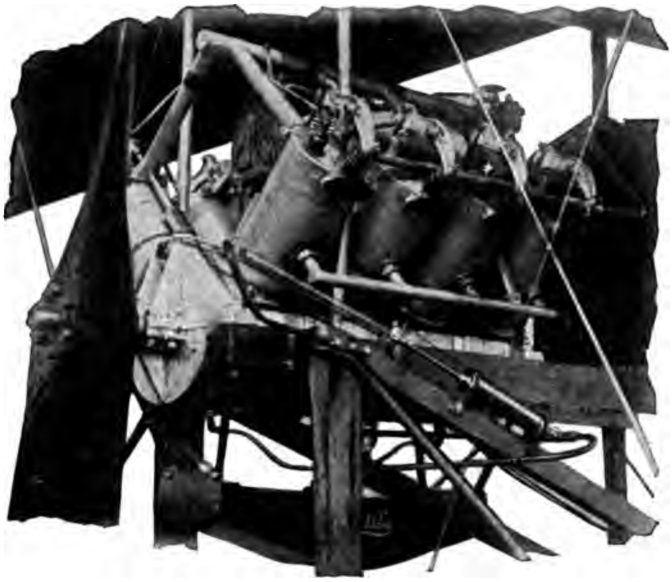


Fig. 11. Curtiss Water-Cooled V-Type Motor

The amazing rapidity with which aviation has progressed during the past few years has been responsible for the entrance of a number of motor manufacturers into the field, many of whom are already building automobile or marine motors, while others undertook the making of special aeronautic motors from the start. As is naturally to be expected, the majority of the motors turned out by the former class are more or less conventional in their design, though distinguished by special features in some instances, yet not as a whole of sufficient interest to merit detailed description of more than a few that may be regarded as representative of a class.

Four-Cylinder Water-Cooled Type. The first of these is the four-cylinder four-cycle vertical water-cooled motor. This, in brief, is nothing more nor less than a light type of automobile motor, and in some cases no great attempt has been made at weight-saving, as there are several in which the water jackets are of cast iron, integral with the cylinders as in automobile practice.

Harriman. In the Harriman, these were at first replaced by copper jackets and more recently by light sheet-steel jackets autogenously welded in place, thus insuring against leakage. A novel feature of this motor is the fact that the lower ends of the cylinders are threaded and screw directly into the crank case and lock, the usual flange and bolt fastening being done away with. Both valves are placed side by side in the head and are operated by a superimposed cam shaft placed between them and driven by a vertical shaft and bevel gears from the crank shaft. The same cam operates both the inlet and exhaust valve in each case. The water jacket of the cylinder head, and the valve ports are cast with the cylinder, the jacket of the barrel being of sheet steel as mentioned. An auxiliary exhaust port in the form of a series of holes drilled in the cylinder castings and uncovered by the piston at the lowest point of its stroke aids in quickly scavenging the cylinders. The Harriman is one of the few aviation motors on which the option of battery ignition is offered, the Atwater-Kent system being employed. These motors are built in two sizes, 30 and 50 horse-power and are designed to run at 1,400 r. p. m. Their weight is four pounds per horse-power.

Horizontal-Opposed Type. On one hand there has been a demand for a simpler and lighter motor to give the same power as the type just mentioned, and on the other for greatly increased power. The former has been met by the horizontal-opposed type.

Detroit Aero. An example of this is the Detroit Aero, which with cylinders of 5½-inch bore by 5-inch stroke is rated 25 to 30 horse-power at 1,500 r. p. m. The valves are located in the head and actuated by tappet rods and rocker arms. Cooling is by air direct, the arrangement of the cylinders lending itself with great advantage to this. Quite a number of this type of motor are now being used in France where they were never regarded favorably for automobile work.

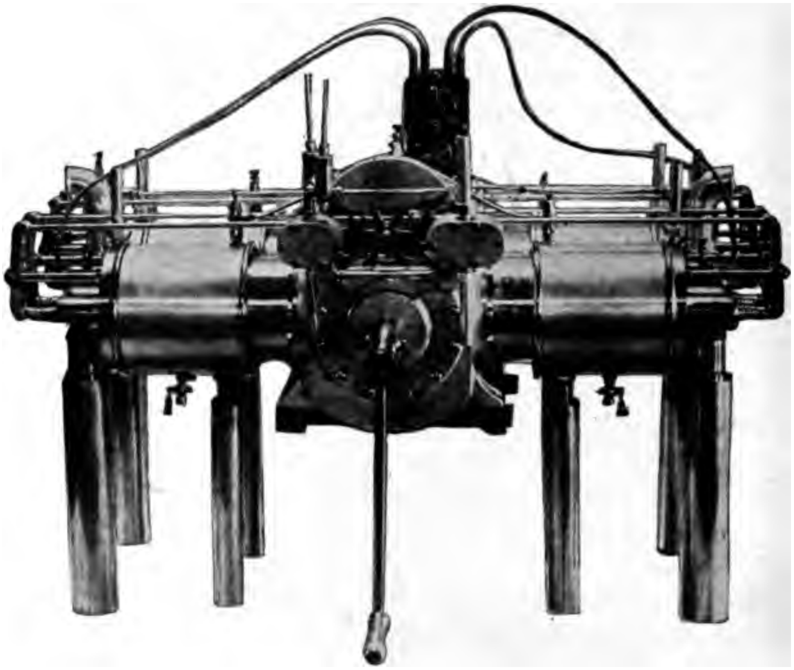


Fig. 12. Call Aviation Motor Fitted with Mufflers

Call. A specially-designed horizontal-opposed type is the Call aviation engine, Fig. 12. This has four cylinders opposed in two pairs, the dimensions being, bore 6 inches, stroke 5¼ inches, and rated at 90 horse-power. It is also built as a two-cylinder opposed rated at 45 horse-power. The cylinders are of a vanadium alloy iron, machined inside and outside and pressed into magnalium (a very strong and light aluminum alloy) water jackets. To save weight, the cylinders are cast of the usual thickness at the combustion chamber, extending down as far as the stroke of the piston, and from there on to the crank case are only half as thick. It is claimed that this construction in connection with the unusually light jackets gives a weight per horse-power equal to that for the cylinders of the customary construction. Ribs extend inwardly from the magnalium jacket and press tightly against the machined outer surface of the cylinder, thus reinforcing the combustion chamber. The cylinder heads are of the same construction as the cylinders, the main portion being of magnalium which is lined with a circular plate of iron over the combustion chamber. Both valves are mechanically operated and are in cages in the head. The valve seats are water cooled while the cages are air cooled to save weight. These cages are cast very thin and have cooling flanges to protect the valve stem bearings. The pistons, cast of the same iron as the cylinders, are provided with internal cooling flanges on the heads. Magnalium is also employed for casting the crank case, numerous internal ribs amply reinforcing it. Lubrication is by the splash system, the supply being

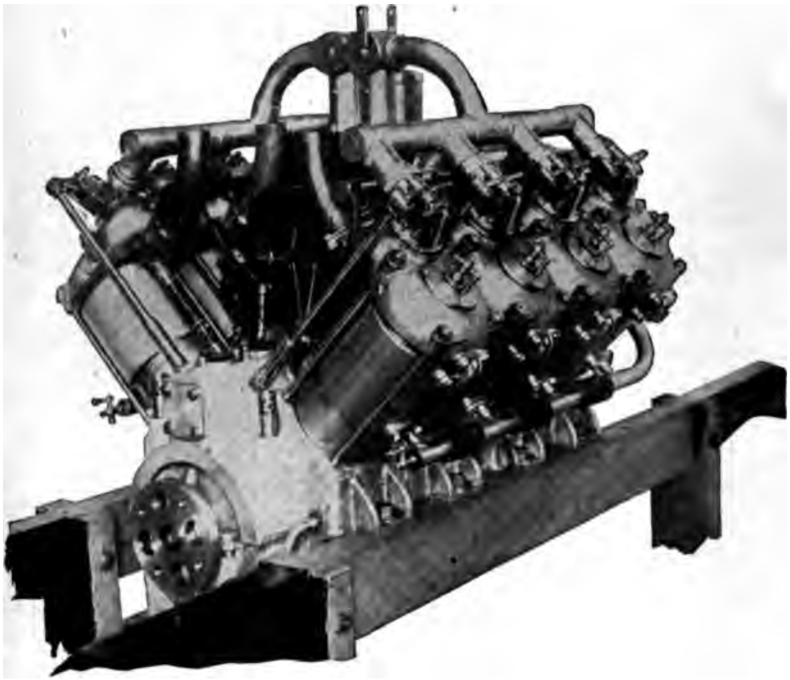


Fig. 13. 65-Horse-Power Indian Aeromotor, Hendee Manufacturing Company

maintained by individual oilers in the form of large cups on the tops of the cylinders. A quick exhaust is insured by the use of large valves with a full lift of approximately one-fourth the valve diameter, supplemented by auxiliary exhaust ports at the end of the stroke. The Call engine is the first aeronautical motor to be fitted with a muffler. Silencers of special design without the usual tubes or baffle plates are fitted directly to the exhaust valves and auxiliary exhaust ports of every cylinder, extending straight downward. The weight of the 45-horse-power motor is 135 pounds, and of the 90-horse-power type, 225 pounds, or 3 and 2.5 pounds per horse-power, respectively.

Fig. 14. Hamilton Eight-Cylinder V-Type Motor

Eight-Cylinder V-Type. *Hendee.* The Hendee aviation motor may be cited as an example of the eight-cylinder V-type, Fig. 13. No attempt has been made to achieve extreme lightness, the object being rather to provide a motor that will carry full load for long periods. The cylinders and heads are cast separately, the former having a light brass water jacket spun into grooves and the joint brazed. The heads have separate jackets connected to the cylinder jackets by a flexible joint. Both valves are placed in an out-board port on the inner sides of the cylinders, the inlet valve being placed on top and operated by a rocker arm while the exhaust is operated direct. The inlet valve is carried in a cage held in place by a breech-block lock; its removal exposes the exhaust valve and permits its withdrawal. The cylinder dimensions are 4-inch bore by 4½-inch stroke, the output being 60 to 65 horse-power, and the weight 260 pounds, or 4.3 pounds per horse-power. Curtiss used one of these motors in the long-distance flights at the Harvard Aviation Meet.

Hamilton. The Hamilton motor, Fig. 14, is of the conventional eight-cylinder V-type, but is distinguished by an unusual valve operating mechanism most of the details of which will be apparent from the photograph. Both valves are placed in the cylinder heads, and the entire valve-operating mechanism is superimposed on them. The vertical tube visible in the foreground between the cylinders is a crank-case "breather" or vent.

Two-Cycle Motors. *Roberts.* As already mentioned, the aeroplane affords an excellent field for the two-cycle motor in view of the constant power requirements, similar to the condition obtaining in marine work. A representative motor of this type is the Roberts, designed by E. W. Roberts, whose experience in the field of aviation dates back to 1894 and 1895 when he served as assistant to Hiram S. Maxim in his experiments at that time. The Roberts two-cycle aviation motor is of the customary three-port type except that instead of opening the admission and exhaust by means of the piston, a special tubular rotary valve is employed, it being claimed that this effects better control of the opening to the crank case and greater economy. The cellular by-pass fitted to Roberts marine motors is also employed to prevent back firing or explosions in the crank case. The cylinders are of hardened steel, their dimensions being 4½-inch bore by 5-inch stroke. Part of the water jacket is cored out of the cylinder casting while the remainder is covered with an aluminum jacket caulked into a groove in the cylinder itself. The pistons and rings are of cast iron and the crank case of magnalium. Ignition is by means of a Bosch magneto with a special advance device as it is impractical to operate the two-cycle motor with a fixed ignition point, it being necessary to retard the explosion timing considerably in order to start without danger of the motor kicking back. To effect this a helical gear is employed to turn the armature of the magneto with relation to the drive. The four-cylinder Roberts motor with carbureter and magneto weighs 165 pounds and develops 52 horse-power at 1,400 r. p. m., while the six-cylinder weighs 220 pounds and develops 78 horse-power at 1,500 r. p. m,. or 3.17 and 2.8 pounds per horse-power, respectively.

Fox. The Fox aero motor is another two-cycle type that is distinguished by the use of a special fourth port. Apart from this, the motor is of practically the conventional three-port type. This fourth port, known as an *accelerator,* is an opening placed below the third port and is designed to admit air alone, which goes through a by-pass on the side of the cylinder, where the fourth port is uncovered by the upward stroke of the piston immediately after the opening of the third port. The incoming fuel charge through the latter is deflected toward the bottom of the crank case, while the air entering through the fourth part is deflected upward and is pocketed under the piston until the opening of the intake port, entering the explosion chamber in advance of the fuel charge. It accordingly serves to drive out the exploded gases in advance of the entrance of the fresh fuel, thus increasing the power and making the motor more economical. The external opening of this fourth port is directly controlled by the operator through a lever, so that it may be closed entirely, when the motor will operate as the usual three-port type; or it may be opened full when greater speed and power are required, which accounts for the name given it. These motors are built in sizes ranging from 36 horse-power, weighing 150 pounds, up to 200 horse-power, weighing 850 pounds, the cylinder dimensions of the smallest size (four cylinders) being 3½ by 3½ inches, and the largest (eight cylinders) 6×6 inches, the average weight per horse-power being about 4 pounds. The cylinders are placed in line in all the sizes.

Elbridge. A two-cycle motor with which a number of successful flights were made by amateur aviators during 1910, is the Elbridge aero special. This is a four-cylinder, vertical, three-port type and it is claimed by the makers that it will carry almost its maximum load up to as high a speed as 2,000 r. p. m. Without the magneto it weighs slightly less than 150 pounds and delivers 50 to 60 horse-power.

Rotary Type. *Adams-Farwell.* The Adams-Farwell, Fig. 15, which is the prototype in this field, was first used for automobiles in 1898 and has recently been redesigned for aviation purposes. In some respects this motor is very similar to the five-cylinder revolving motors used in the Adams-Farwell automobile, having the same number of cylinders, the same single throw crank, the same positive oiler, and the same crank construction. In other respects, however, it is quite different, being designed solely for aviation purposes, and revolving in a vertical plane, so that it may be direct connected to propeller shaft or have the propeller mounted directly upon the motor for aeroplane work.

The most interesting improvement found on this motor and, no doubt, the most important advance made in the construction of aviation motors since the introduction of the revolving cylinder type, is the elimination of the carbureter and employment of fuel injection with a means for regulating the amount of gasoline injected into each cylinder, and insuring that all cylinders will receive exactly the same mixture. This also makes it possible to do away with the inlet valve, and employ one valve for both inlet and exhaust, as only air is drawn in by the suction stroke of the piston, while the gasoline is sprayed within the cylinder where it is mixed with the charge of air before compression. Having but one valve in the head of the cylinder it can be made amply large to insure a full charge and a free exhaust.

Fig. 15. Adams-Farwell Revolving Aeronautical Motor

In order to relieve the cam controlling the action of all five valves from the heavy load of opening a large valve against the high pressure at the time exhaust takes place, the cylinders are provided with auxiliary exhaust ports, which are uncovered by the piston on its downward stroke. No check valves are required over these auxiliary ports, as, on the suction stroke, pure air and not a mixture of gas is drawn in, so what air is drawn in through the auxiliary ports on the suction stroke becomes a part of the explosive mixture in the cylinder, and being a constant quantity does not affect the operation of the motor.

The control of the motor is entirely taken care of by regulating the amount of gasoline used, and the only adjustment that might be construed as belonging to the carburetion system, is the valve by means of which this control is accomplished. The motor is not sensitive to adjustment, and the speed may be regulated through quite a wide range by this simple means.

The lubrication system mentioned consists of a simple and ingenious oiling device that is a patented feature of the motor and represents a great advance over the present wasteful method of lubricating rotary motors. This oiler consists of a single rotary member much resembling in form the cylinder of a revolver, with longitudinal chambers bored therein. Each of these chambers carries a plunger which, as the cylinder revolves, is driven from end to end by two stationary cams, causing a small amount of oil to be drawn in to each of the chambers at the bottom and ejected into a corresponding tube at the top. This oiler supplies cylinder oil of an extra heavy grade to the various bearings and to the cylinders, doing away with the necessity for splash lubrication, which calls for the flooding of other revolving cylinder motors with a great quantity of oil that dirties the valves and soots up the spark plugs.

There are two spark plugs in each cylinder of this motor, and two independent ignition systems are employed, so that either or both of the set of plugs may be used, thus insuring against the accidental stoppage of the motor from a broken wire.

Something over ten years ago, the Adams Company conducted a series of experiments to determine the action of the air in circulating about the cylinder of a revolving cylinder motor, and, as a result, established beyond question the fact that longitudinal ribs are much more efficient than the circular type. The air coming in contact with the cylinder walls is thrown off radially, circulating lengthwise of the cylinders, so the only logical arrangement of cooling ribs is lengthwise of the cylinders. The placing of ribs in this way has the further advantage of strengthening the cylinder against tensile strain caused by the action of centrifugal force, and the explosion.

This new motor operates satisfactorily on low-grade fuels, but when these grades are employed, it is desirable to have a small tank of gasoline of higher specific gravity to facilitate starting. Reliability has been considered above extreme light weight, as evidenced by the large connecting-rod bearings, the liberal size of the crank shaft, and the fact that four rings are employed on the piston where some builders of aviation motors are using only a single ring. Vanadium chrome nickel steel is used wherever practicable. The dimensions are 6-inch bore and stroke, and at 1,000 r. p. m. the motor is rated at 72 horse-power. It drives a 9-foot 6-inch propeller of 6-foot pitch at 900 to 1,000 r. p. m., developing a thrust of 440 to 460 pounds, which can be maintained indefinitely without overheating the motor.

Brooke "Non-Gyro" Motor. This is another American motor of the rotary type of recent development. It is made in Chicago and is distinguished by several new features that should make it of value for aeronautical purposes, and particularly for aeroplane work. The Type "E" Brooke motor, which lists at $2,500, has 10 cylinders, arranged in two units of five each, either of which may be run independently of the other when desired. With all 10 cylinders working, the motor is rated at 85 horse-power. The cylinders are offset slightly on the crank case and measure 4¼ by 4¼ inches. Two Stromberg carbureters are employed, one for each unit, while a two-cylinder type of magneto takes care of the ignition of all 10 cylinders, there being but one foot of high-tension cable necessary and no moving contacts, making a very simple and positive ignition system that should prove of great value, as the ignition is a weak point in even the best of motors and its failure through trivial causes is hard to guard against where a number of small parts and a great deal of wiring is necessary. Another improvement is the elimination of the wasteful method of "shooting" oil through the motor for lubrication, as in the Gnome, a nine-tube, force-feed oiler being employed instead. The intake valves are placed in the piston heads, while the exhaust valves are in the cylinder heads. Light springs are used to keep the valves in place when the motor is idle, but they have no function to perform when it is in operation.

Weinberg. An interesting development of this kind is the Weinberg, two-cylinder, horizontal-opposed, air-cooled motor, a Detroit product. The crank shaft is stationary while the cylinders revolve about it, centrifugal force being taken advantage of to draw in the charge through the hollow shaft and to exhaust it. During the outward stroke of the pistons a vacuum is created in the crank case, drawing in the mixture of fuel and lubricating oil, a check valve between the carbureter and crank case preventing its escape on the return stroke. When the piston reaches the lower limit of its stroke, the charge enters the combustion chamber through a by-pass, the motor accordingly being in reality a two-cycle type with an independent exhaust valve. The latter is mechanically opened by means of a rocker arm. This valve is located in the cylinder head and is very large—almost two-thirds the cylinder diameter. Centrifugal force keeps it closed between explosions so that no valve spring is required. The cylinders and pistons are cast iron machined all over, while the crank case is a one-piece casting of aluminum alloy. The magneto is gear driven at the same speed at which the cylinders revolve, the current being distributed to the spark plugs through a revolving sector. Both cylinders fire simultaneously.

Metz. The Metz is a four-cycle, seven-cylinder revolving motor of unusually large size, Fig. 16, the cylinders having a bore and stroke of 6¾ inches. It develops 125 horse-power at 800 r. p. m. and weighs 375 pounds, or exactly 3 pounds per horse-power. The cylinders are of chrome steel machined direct from hollow forgings with very thin integral flanges for air cooling. They are attached to a drum-shaped crank case cast of alvanum, another aluminum alloy of great strength and lightness, mounted on large annular ball bearings. The stationary crank shaft and crank pin are of chrome nickel steel. Both valves are placed in the cylinder heads and are mechanically operated. The valves themselves are nickel steel while the push rods for operating them are light tubes of the same metal. Instead of feeding the mixture up through the pistons as in the Gnome revolving motor, it is led from the crank case to each of the inlet valves through light copper pipes. The fuel and lubricating oil enter the crank case through the hollow crank shaft, centrifugal force being relied upon to distribute the lubricant. The pistons are very light and are fitted with a novel type of floating piston ring.

Weight per Horse-Power Hour. It will be noted that in very few of the cases mentioned does the weight of the motor exceed four pounds per horse-power; in the majority it is between two and a fraction of this figure, or say an average of three pounds. This, of course, refers to the motor alone; in the case of water-cooled motors the addition of the radiator, water supply, gasoline tank, and similar fittings will usually increase the weight by almost a pound per horse-power. Even at that it will be evident that improvements in construction and a disregard for the cost of the finished product have accomplished wonders where the reduction of the weight is concerned. It is not too much to say that even the heaviest of the

Fig. 16. Metz Seven-Cylinder Revolving Motor with Nickel-Steel Cylinders

motors in question is a remarkably light power unit. But there is a factor that is of greater importance in the result than that of the weight per horse-power. This is the weight per horse-power hour as explained in Dirigible Balloons, page 25.

FOREIGN MOTOR TYPES

As with the automobile, the French took up the aeroplane and its motive power with all the energy and enthusiasm they possess, right from the start. Even before the Wrights made their first public flights in France, interest was widespread and much had been accomplished. The same spirit was not infused into the art on this side of the Atlantic until 1910 and even then the number of investigators devoting their attention to it, the number of machines in existence, and the number of men who could actually fly, were but a small fraction of those engaged in the pursuit of aviation in France. This briefly explains why so much attention has been devoted to the development of the aeroplane motor abroad, as shown by the following examples, the majority of which are of French construction.

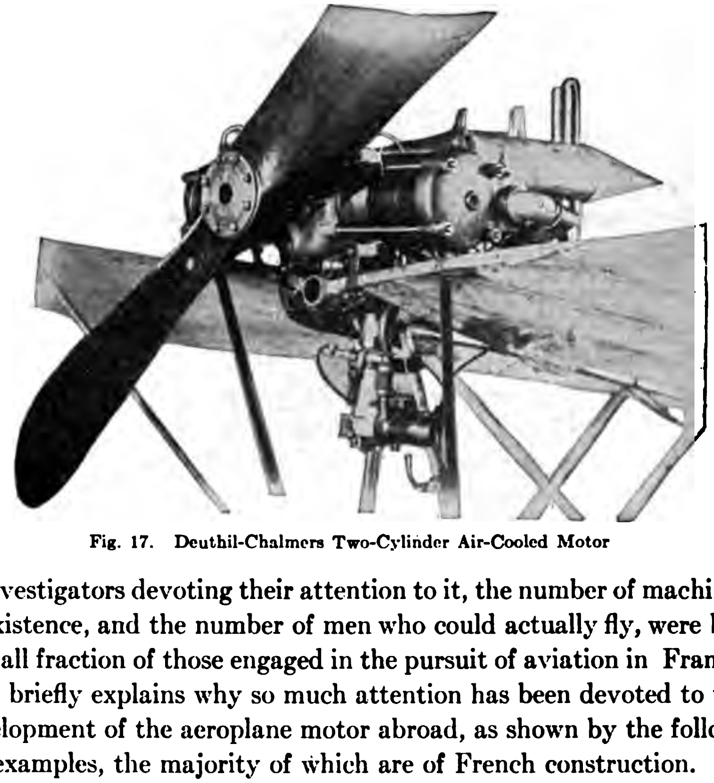


Fig. 17. Deuthil-Chalmers Two-Cylinder Air-Cooled Motor

Horizontal-Opposed Type. *Deuthil-Chalmers.* There is, however, an American *note* in this development, if it may be so called, and that is the adoption of the two-cylinder, horizontal-opposed motor—a purely American type—for very light units. The best representative of this class is the Deuthil-Chalmers 20-horse-power, air-cooled motor used to drive Santos-Dumont's Demoiselle. Following the precedent of so many other makers, later models of this motor are water cooled, Fig. 17. The first air-cooled, two-cylinder type weighed but 48.5 pounds, or 2½ to 2¾ pounds per horse-power, while the later model, and particularly the four-cylinder type, weighs 4 pounds per horse-power. The connecting rods of each pair of cylinders are attached to a common crank, while instead of the usual fly-wheel, a wire spoke wheel resembling bicycle construction, is employed. Cylindrical valves, both of which are mechanically operated, are placed in the heads, the cylinders being attached to the drum-shaped crank case by means of long stay rods which pass through clamps over the cylindrical heads. The spark plugs are placed in the upper sides of the heads with the water outlets close to them, the water intake being on the under side. Special oil-feeds are run to the cylinders to lubricate the pistons, splash not being depended upon for this purpose. The complete motor is attached to the aeroplane by two bolts passing through lugs cast in the crank case.

Fig. 18. Darracq Two-Cylinder Motor

Darracq. Another motor of this type is the Darracq, shown in Fig. 18. This is also a water-cooled motor, most of the constructional details of which are apparent in the photograph. Both valves are mechanically operated by rocker arms and push rods actuated by a pair of eccentrics completely housed in, this being a distinction from the general practice in aviation motors, the timing gears usually being exposed as in the original automobile motors. The magneto is mounted at an angle on top of the crank case, while both the carbureter and the oil tank are suspended below it, a pump immersed in the tank itself distributing the lubricant.

Clement. In the Clement motor of this type, both the oil and water tanks are combined and are mounted over the crank case,

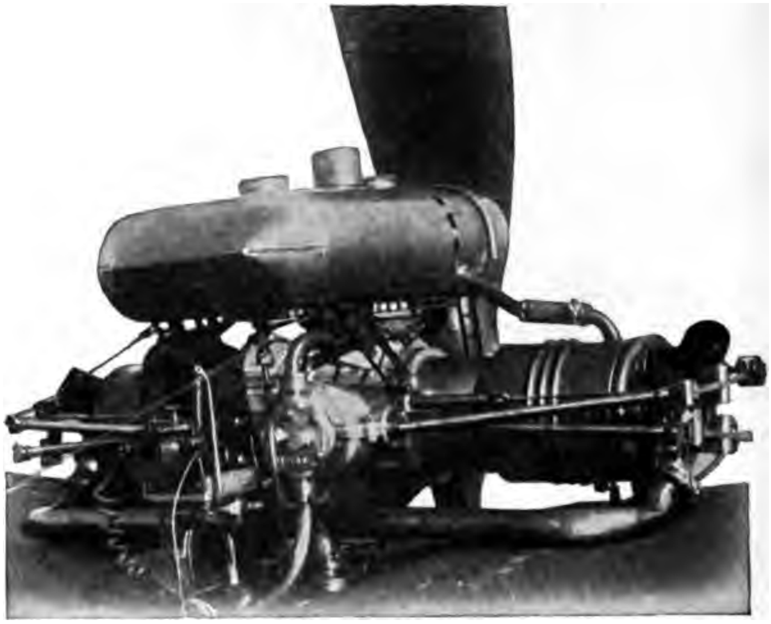


Fig. 19. Clement Two-Cylinder Water-Cooled Motor

as shown by Fig. 19. A similar valve action and arrangement of the carbureter and intake piping are employed as in the Darracq, while the magneto is mounted alongside the gear type water pump at the back of the motor.

The next class in what may be termed the order of development is the conventional four-cylinder vertical type, many of which, however, are distinguished by unusual features.

Conventional Four-Cylinder Type. *Wright-Barriquand.* Of the more conventional types, the Wright-Barriquand (French Wright

motor) differs from its American prototype only in slight detail, the principal feature being the use of mechanically-operated inlet valves. (See Fig. 20.)

Panhard and Primi-Berthand. **The Panhard and Primi-Berthand, Figs. 21 and 22, are similar in so far as their cooling arrangements are concerned. That is, both have light sheet-copper jackets of corrugated section to increase the radiating surface. But the former is a four-cycle type with the valves in the head operated by rocker arms, while the latter is a two-cycle engine, as will be apparent from the photo, which illustrates the carbureter and the method of drawing the fuel mixture into two outside chambers, which communicate with the cylinders through the ports shown, these being opened by the pistons at the lower end of the stroke.**

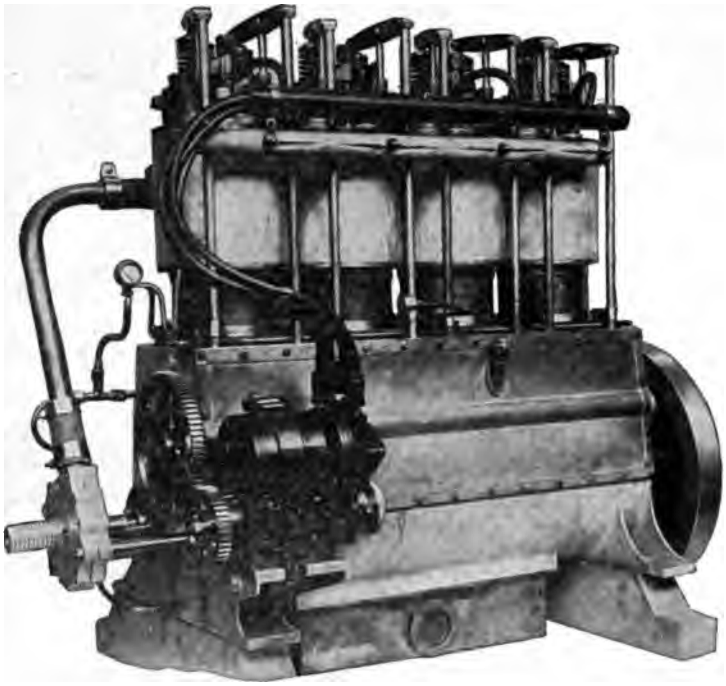


Fig. 20. Wright-Barriquand (French Wright) Motor

Vivinus. **The Vivinus, Fig. 23, is another aviation motor that has been directly developed from the automobile type of the same make. No attempt has been made to achieve lightness, the**

motor weighing 300 pounds for an output of only 50 horse-power, or 6 pounds per horse-power. But trials have shown it to be capable of sustained operation without power losses, it having been employed successfully on a Farman biplane in England. As the illustration shows, a pressed-steel flywheel is employed.

Fig. 21. Panhard Aviation Motor

Other Vertical Cylinder Types. Motors of a generally similar type, the chief features of which are evident from the illustrations, are the De Dietrich, Fig. 24; M. A. B., Fig. 25; Aster, Fig. 26, and the Buchet six-cylinder, which is shown mounted on the framing of a Bleriot monoplane in Fig. 27. It will be noted that the propeller in this case is depended upon to take the place of the flywheel. Practice shows this to be permissible when six or more cylinders are employed, although its omission is not infrequent even on a four-cylinder motor, as will be noted by reference to the Gregoire,

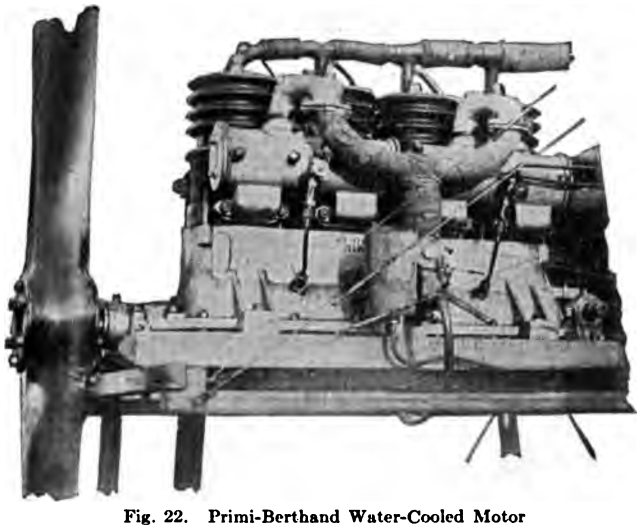


Fig. 22. Primi-Berthand Water-Cooled Motor

mentioned farther along. The flywheel also has been eliminated even when no more than two cylinders are employed as in the Deuthil-Chalmers horizontal-opposed type already described. To say the least, it is not good engineering practice, particularly in two- and four-cylinder types, as there is a well-defined interval between the impulses in both of these. In the six- and eight-cylinder types in which the impulses always overlap, giving a continuous torque, even the slight weight of the wood propeller blades revolving at such a great distance from the hub is sufficient to compensate for the lack of a flywheel,

Fig. 23. Vivinus Aviation Motor

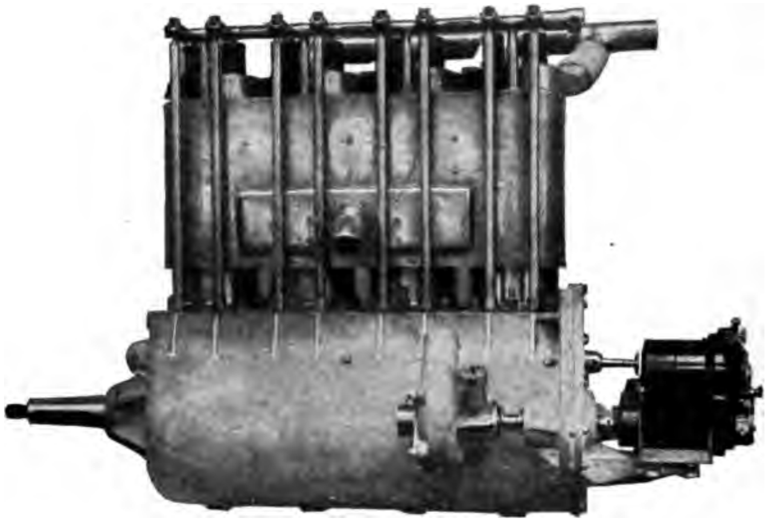


Fig. 24. De Dietrich Motor

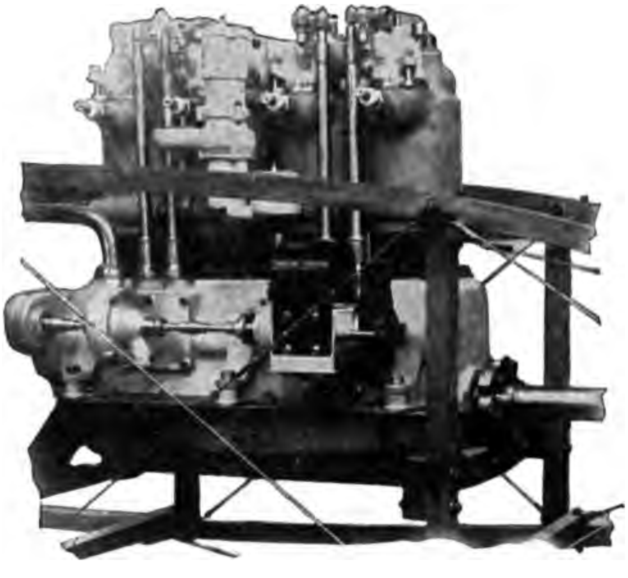


Fig. 25. M. A. B. Aviation Motor

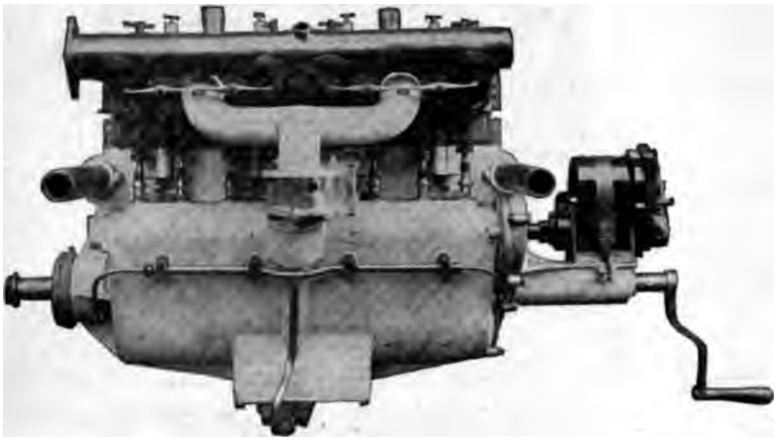


Fig. 26. Aster Aviation Motor

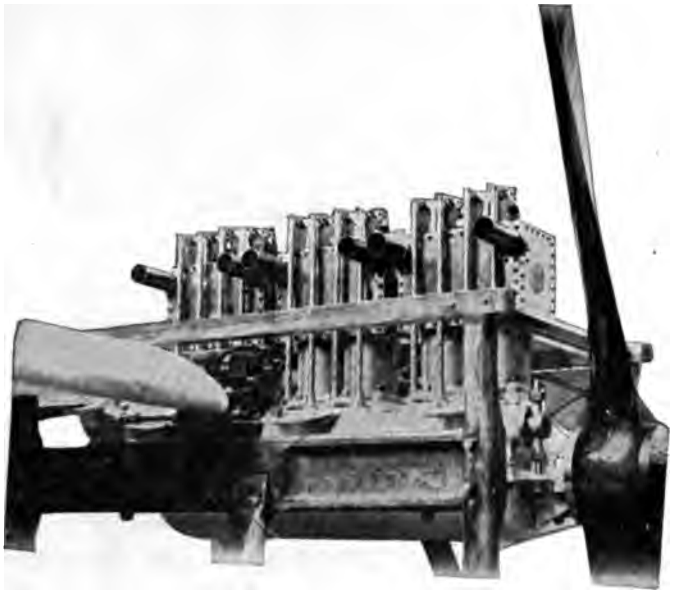


Fig. 27. Buchet Six-Cylinder Mounted on a Bleriot Frame

but it is safe to say that the operation of all these motors would be improved by the use of a flywheel, which would add but very slightly to their total weight.

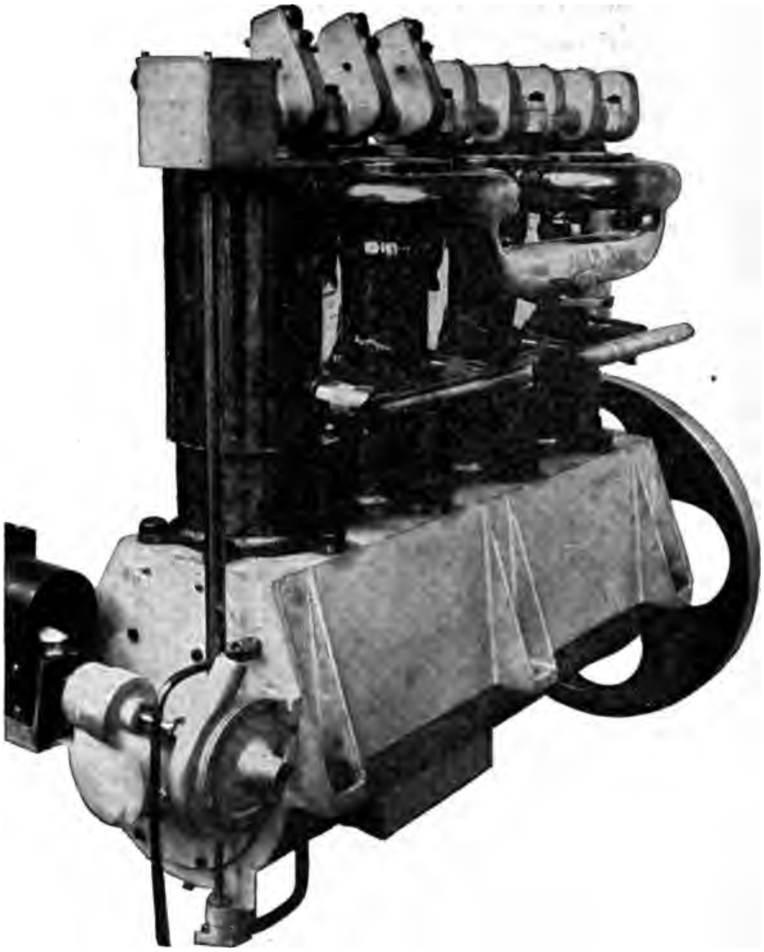


Fig. 28. Green Motor with Superimposed Cam Shaft

An instance of the employment of a superimposed cam shaft is found in the Green, Fig. 28, a motor of English design, while the Gregoire, already referred to, and illustrated by Fig. 29, shows the use of an integral radiator which permits of greatly reducing the weight by cutting down the amount of water required to a fraction of that ordinarily necessary. This radiator consists of four banks of light copper tubes of small diameter the forward sections of which have two rows of tubes while the after ones have but one row. These tubes terminate in headers at top and bottom on much the same principle as the water-tube boiler, the upper or main headers being of considerably greater diameter than the lower ones. These headers extend entirely across the cylinder heads and outboard for some distance and are connected with the water jackets at the valves, or hottest part. The lower headers are in two parts, directly attached to the lowest part of the jacket at right angles. As the water heats it rises in the large, vertical, uptake tubes, spreads across the upper headers and drops through the banks of small tubes which are cooled by the wind, the circulation being entirely on the thermo-syphon

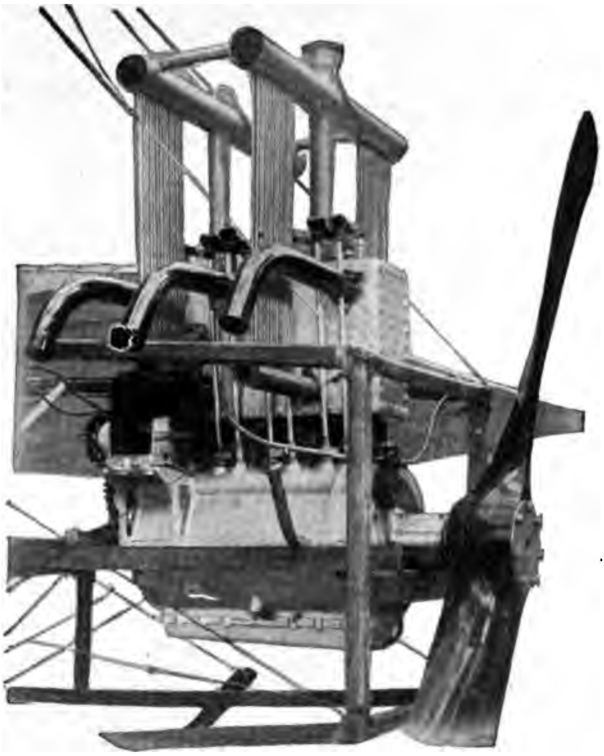


Fig. 29. Gregoire Motor with Directly Attached Radiator

principle. The four-cylinder motor shown in Fig. 30 is noteworthy chiefly owing to the fact that the very radical departure of incorporating a gear drive between the crank shaft and propeller connection as an integral part of the motor has been tried.

Fig. 30. Four-Cylinder Type with Gear Drive to Propeller Shaft

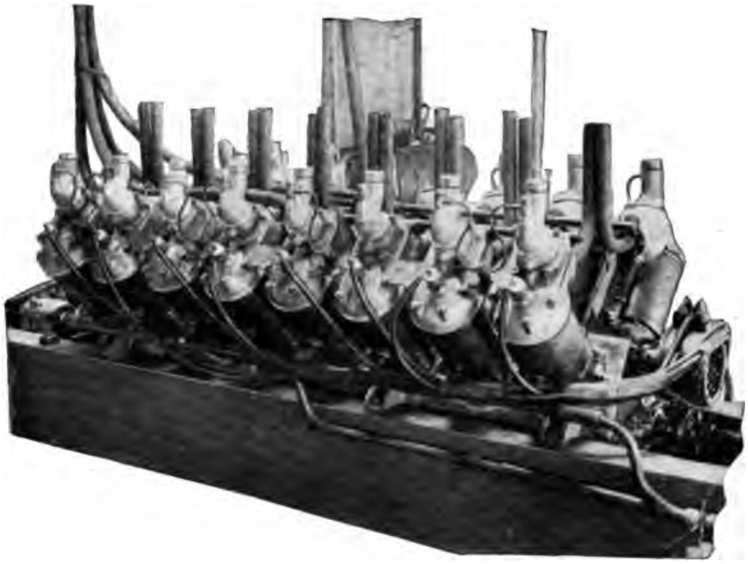


Fig. 31. 100-Horse-Power Sixteen-Cylinder Antoinette Motor

V-Type. *Antoinette.* From the four-cylinder to the eight-cylinder **V**-type motor is a logical step in the problem of weight saving as this type permits of the use of the same form of crank shaft of scarcely greater diameter, each opposite pair of cylinders having the big ends of its connecting rods attached to a common crank pin. The Antoinette is the most prominent instance of this, a sixteen-cylinder motor of this class rated at 100 horse-power being shown in Fig. 31. One or two of these have been employed in the Antoinette racing monoplanes, but the eight-cylinder engine shown by Fig. 32, is more commonly employed. This is rated at 55 horse-power and is a later model than the sixteen-cylinder motor shown, having the cylinder heads and valve seats made in one piece from light steel drop forgings, instead of being cast separately as heretofore. The cylinders are machined inside and outside and the valves are placed one above the other in chambers, the inlet valves being automatic, individual plunger pumps being employed to inject the fuel directly into the valve opening. These pumps are operated by variable throw eccentrics, the travel of which may be adjusted by means of the hand wheel back of the motor which is within reach of the aviator. This controls the amount of power developed by adding or decreasing the amount of gasoline in the mixture, instead of throttling the latter as is ordinarily done. The water jackets are of pure copper and are deposited directly in place on the cylinders by

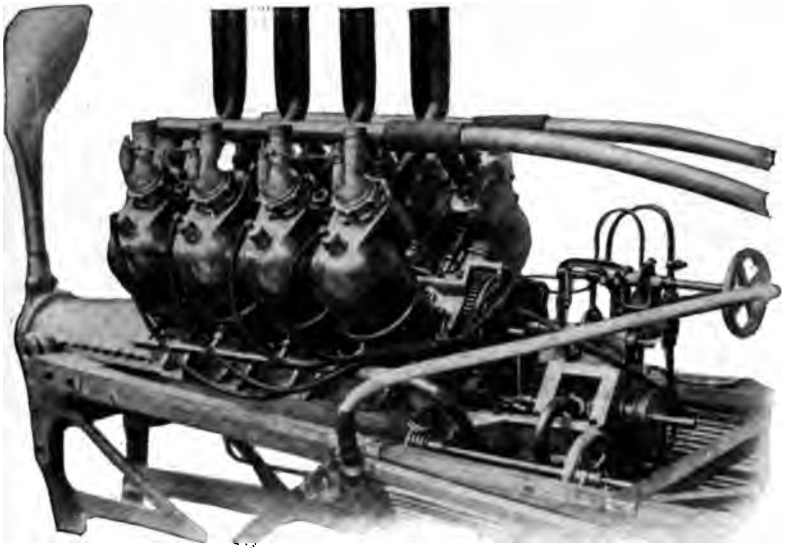


Fig. 32. Eight-Cylinder Antoinette Motor

an electrolytic or plating process. There are thus no joints whatever and the jackets are very light and strong, the method of attaching them to the cylinders being patented.

The water pump is placed at the rear end of the crank shaft in a special casing, a pulley on an extension of the pump shaft carrying a belt which drives a smaller water pump placed at the bottom of the panel of condenser tubes which form part of the triangular forward part of the body of the Antoinette monoplane. These tubes are less than one-half inch in diameter and are extremely light and flexible, their weight forming four-fifths of the complete weight of the condenser, while the headers connecting the tubes constitute the remainder. Horizontally mounted back of the motor is a cylindrical tank employed to separate the steam and water coming from the jackets. At the top of this tank is a pipe leading to the condenser, to carry off the steam collecting in the upper part of the tank. Upon being retransformed into water, it is returned to the tank by the

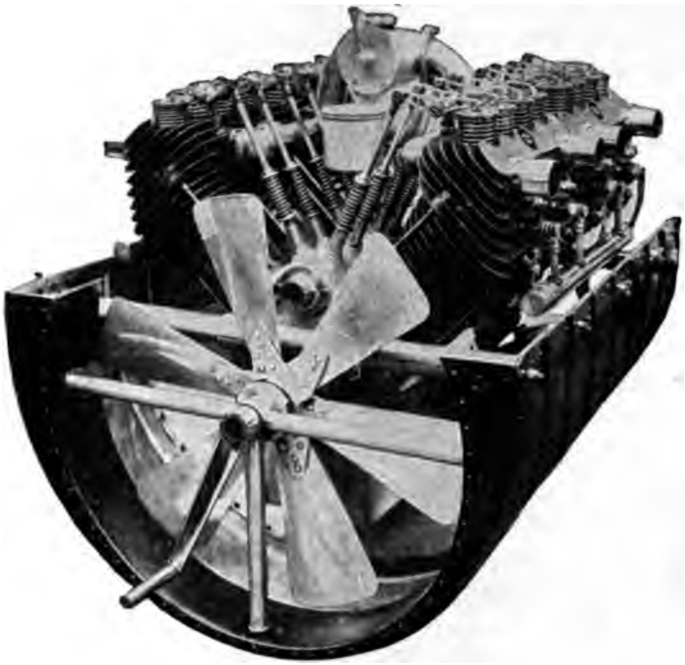


Fig. 33. Fiat Eight-Cylinder Air-Cooled Motor

smaller pump mentioned. This arrangement makes it possible to cool the 55-horse-power motor shown when running constantly under full load, with but three gallons of water. The motor converts one-fourth gallon of water into steam per minute, the condenser having ample radiating surface to take care of this. As mounted along the body of the monoplane, this condenser does not add perceptibly to the head resistance. Owing to the flexibility of the tubes, it could be mounted on the aeroplane surfaces if desired, though the location already adopted is preferable for many reasons.

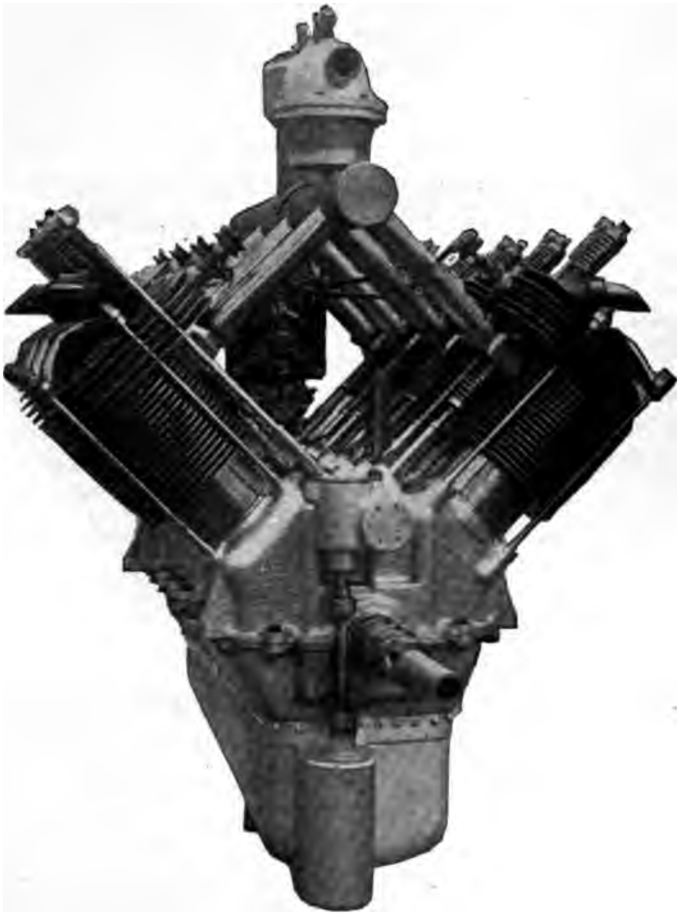


Fig. 34. Renault Air-Cooled Eight-Cylinder Motor. Fan Housing Removed

Fiat. Fig. 33 shows the Fiat eight-cylinder, V-type, air-cooled motor, in which the valve chambers are placed horizontally despite the 45-degree angle of the cylinders. All the valves are mechanically operated from a single cam shaft through adjustable rods and levers. A separate high-tension magneto is employed for igniting each group of four cylinders, the two magnetos being placed on either side of the crank case at the rear and at an angle of 45 degrees. They are driven by external timing gears but are protected from below by the sheet aluminum pan shown, the latter forming one-half of the complete housing of the motor, the upper part having been removed to expose its details. A single carbureter placed between the cylinders supplies them all with fuel. The normal r. p. m. rate is very high—1,700 to 2,000 r. p. m., at which the motor develops 35 to 40 horse-power, its maximum being 50 horse-power. The cylinder dimensions are 4.3-inch bore by 4.1-inch stroke.

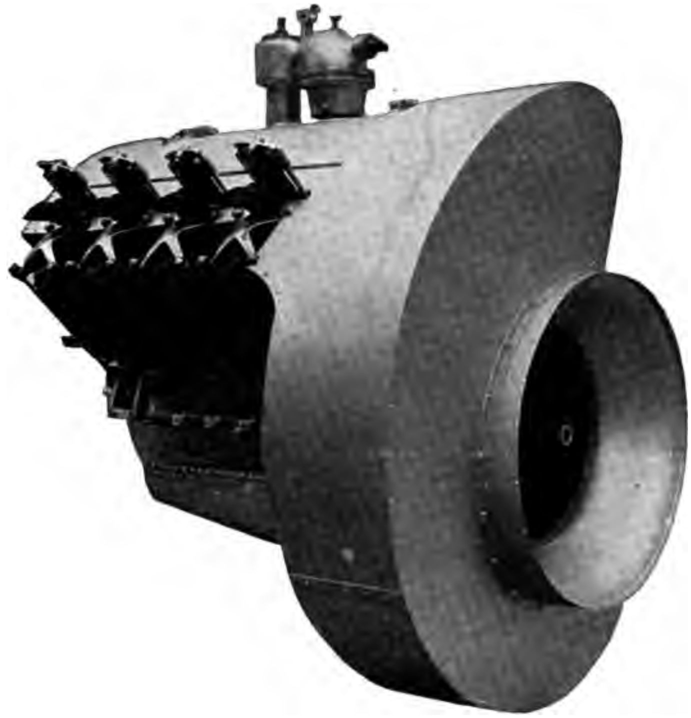


Fig. 35. Renault Air-Cooled Motor with Fan Housing in Place

Renault. Though of smaller dimensions, 3.5-inch bore by 4.7-inch stroke, the Renault air-cooled motor of this type, shown in Fig. 34, is rated at 45 to 55 horse-power with 1,500 to 1,800 r. p. m., the former being its normal speed. In this view it is shown with the air-cooling apparatus removed. All valves are mechanically operated from a single cam shaft, the exhaust being placed directly over the inlet valves, the inlet manifold being so arranged as to obtain the maximum heating effect from the cylinders. An automobile type, automatic carbureter, entirely of aluminum, vaporizes the fuel, and a high-tension magneto is employed to fire the charge. As will be noted, this carbureter is mounted on the upper side of the center of the inlet manifold. Oil is carried in a large tank beneath the crank case to which it is raised by a pump driven through bevel gearings. The motor is designed so that the propeller of the aeroplane may be mounted either on the crank shaft or on the cam shaft, the turning speed being reduced to one-half that of the normal r. p. m. rate of the motor, in the latter case, or 750 r. p. m. This motor has developed as high as 58 horse-power on a dynamometer test. To

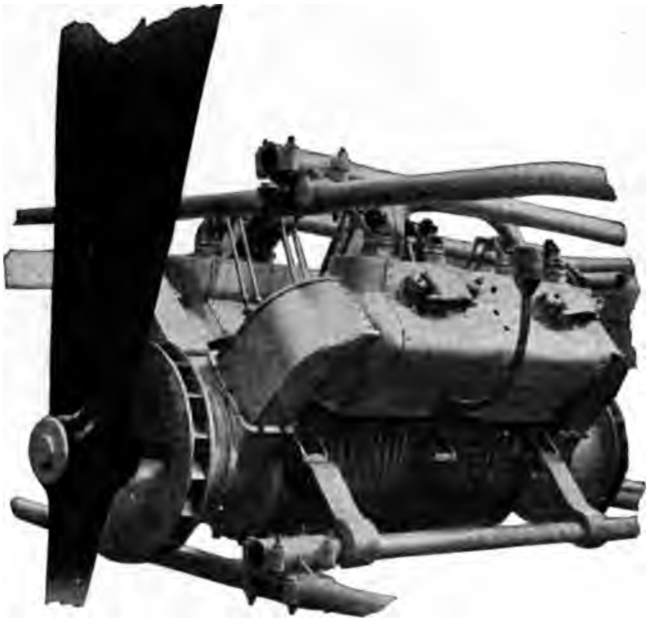


Fig. 36. Pipe Air-Jacketed V-Type Motor

cool it a centrifugal fan of large diameter is mounted in a housing at one end, as shown by Fig. 35. The cold air from the periphery of this fan is led between the cylinders by means of the extended housing shown, finding an outlet at the side between the cooling flanges on the cylinders. Complete with magneto, carbureter, and air-cooling equipment, it weighs 374 pounds, or 6½ pounds per horse-power. It was with one of these motors that Tabuteau won the Michelin prize of $20,000 in 1910 by flying for more than eight hours without a stop, covering close to 400 miles.

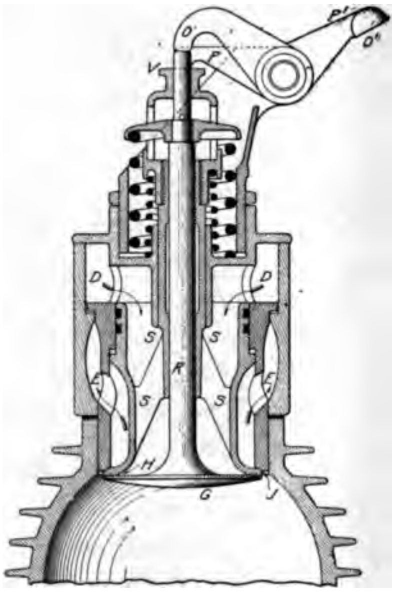


Fig. 37. Combined Inlet and Exhaust Valve of Pipe Motor

Pipe. Another motor of the same type which is air cooled on the same principle as the Renault is the Pipe, of Belgian manufacture, illustrated by Fig. 36. The cylinders are 100 millimeters square, *i. e.*, 3.9 inches bore and stroke. The crank shaft is mounted on three large ball bearings with a ball thrust bearing at one end, the cam shaft also being similarly mounted, with the exception of the provision against thrust. One of the chief features of this motor, apart from the cooling, is the combined inlet and exhaust valve, on the same principle as the Pelterie (French) and the Franklin (American) motors. It consists of a sliding sleeve, bell mouthed at its lower end to form the exhaust valve, and the seat for the inlet valve as well. This is illustrated in section by Fig. 37. The inlet valve *G* is concentric with the sleeve *S*, its stem *R* passing through the hollow stem of *S*, and it seats upon it at *H*. The seat for *S* in the cylinder head is at *J*. The two valves thus formed are provided with suitable retaining springs and are operated by the levers *OO'* and *PP'*. *P* is forked to surround *R* and bear upon the cap *V* surmounting *S*. *S* forms a piston and is provided with two piston rings just below the inlet ports *DD*, to prevent the exhaust gases from leaking into the inlet pipe when being expelled through the exhaust ports *EE*. When *G* is opened by the rocker arm *O*, gas is drawn from the carbureter through *DD* and down through the hollow sleeve *S*. At the end of the working stroke, the sleeve *S* is moved downward from its seat at *J* by the forked rocker arm *P*, the exhaust gases then being expelled through the ports *EE*. The passage of the cool gases through the center of *S* prevents both the inlet and exhaust valves from warping due to the heat and is thus of great advantage on an air-cooled motor. Two blowers of special form, one at each end of the crank shaft, force a large volume of air through the aluminum jackets and over the cooling flanges of the cylinders similar to the American Frayer-Miller engine. The Pipe motor complete weighs 288.8 pounds, or about 5¾ pounds per horse-power.

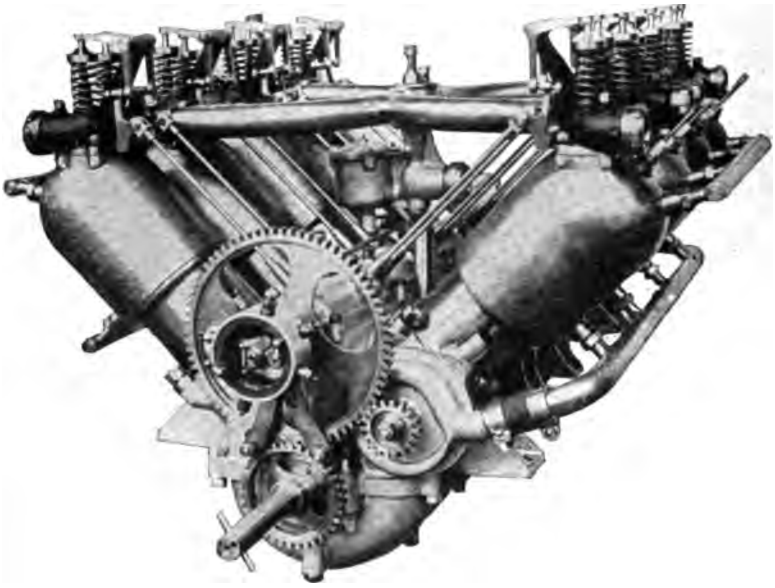


Fig. 38. Bruhot Eight-Cylinder Water-Cooled Motor

Water-Cooled Types. Examples of water-cooled, eight-cylinder, V-type motors are illustrated in the Bruhot (French), Fig. 38, and the Wolseley (English), Fig. 39, two of the latter of 200 horse-power each being used on the ill-fated British airship Mayfly.

Fan and Star Types. *Anzani.* It will be noted that few, if any, of the four-cylinder or eight-cylinder motors just described, whether air- or water-cooled, weigh less than 5 pounds per horse-power, while most of them exceed this. To considerably reduce this figure, the fan or star arrangement of the cylinders has been resorted to. In its simplest form this is shown by the Anzani two-cylinder, air-cooled motor, Fig. 40. In reality, this is nothing more or less than a section of the usual eight-cylinder V-type. Cooling is by means of sheet-metal, perforated flanges pressed on the cylinders.

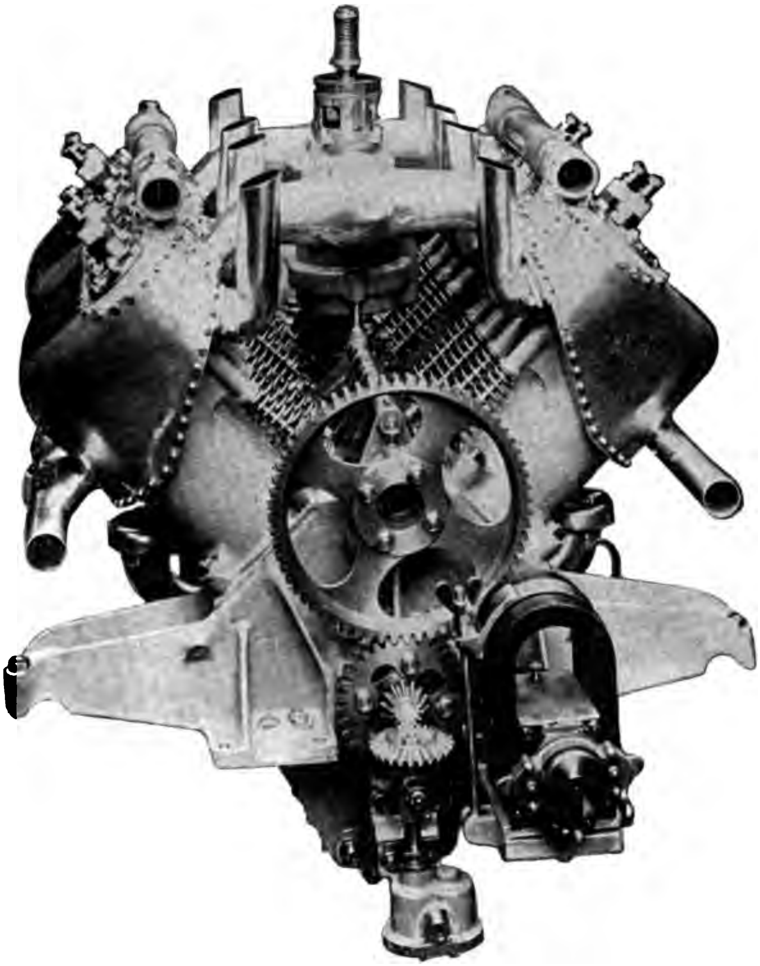


Fig. 39. Wolseley Eight-Cylinder Water-Cooled Aviation Motor

M. A. B. A closer approach to the fan formation is seen in the

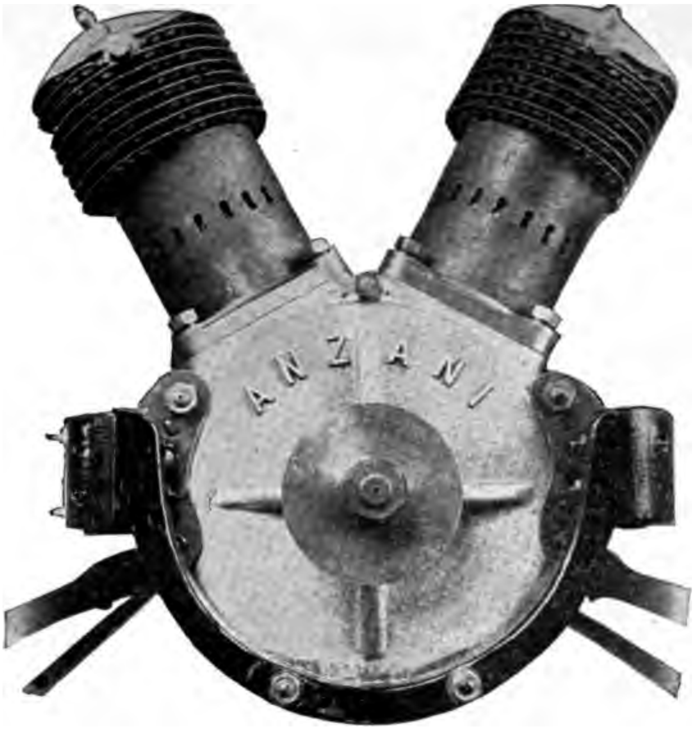


Fig. 40. Anzani Two-Cylinder V-Type Motor

Fig. 41. M. A. B. (Italian) Four-Cylinder Motor

M. A. B. (Italian) four-cylinder motor, Fig. 41. In this case, as in those following, the flanges are cast integral with the cylinders.

Farcot. A further extension of the same principle is shown in the Farcot (French), Fig. 42, this having six air-cooled cylinders. The same makers also manufacture a motor in which the cylinders are mounted radially around a circular crank case, the latter with its cylinders lying horizontally, the crank shaft running vertically. On its upper end it carries a seven-bladed horizontal fan to cool them.

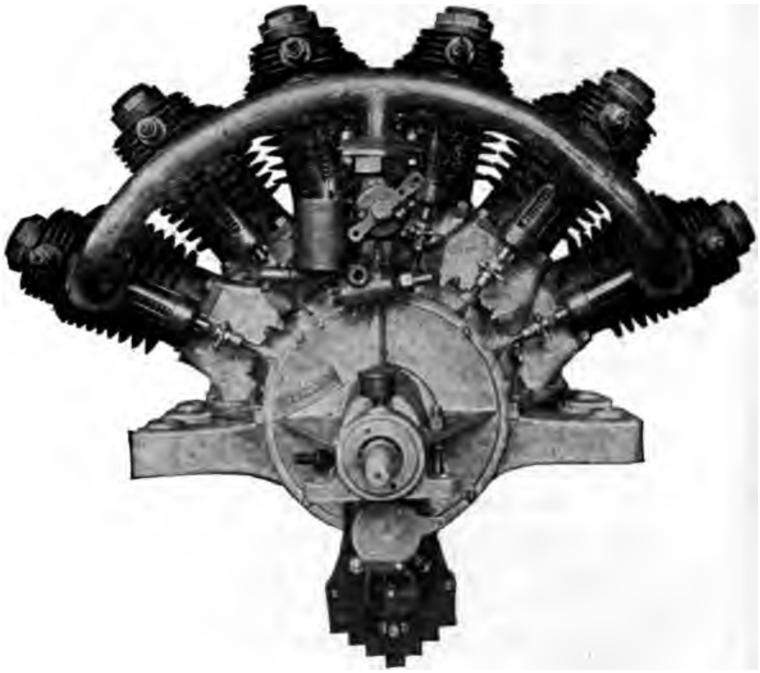


Fig. 42. Farcot Fan Type Air-Cooled Motor

This arrangement of cylinders grouped symmetrically around a central crank case is not new, Forest having employed it in 1888, and Manley in 1900 for aeronautic motors, the former building a 50-horse-power, eight-cylinder motor of this type with the then light weight of 11 pounds to the horse-power. Manley produced a 52-horse-power, five-cylinder motor with a weight of but 2.4 pounds per horse-power, or 125 pounds total weight. It developed full power for ten hours under constant load and was subsequently employed by Professor Langley in his full-sized aerodrome. The number of cylinders and their arrangement in a motor of this type have much to do with the balance, regularity of cycle, lack of vibration, and smoothness of running. A four-cylinder motor of this type is nearly in perfect balance so far as centrifugal force is concerned, a suitable counterweight making up for any deficiency. With two sets of four cylinders working on two cranks at 180 degrees, the balance is better still—the more so the nearer together the planes of the two sets of cylinders. The relative positions of the pistons, connecting rods, and cranks in an eight-cylinder Farcot motor of this type is shown in section, Fig. 43.

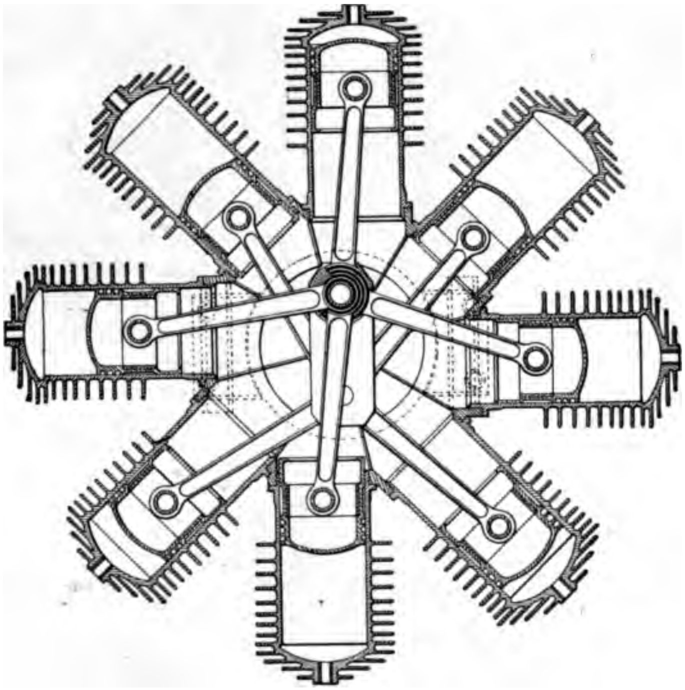


Fig. 43. Cross-Section of Farcot 50-Horse-Power Air-Cooled Motor

Each group of four cylinders is necessarily in a different plane to permit of attaching the different connecting rods to the two cranks, but by offsetting the rods, the distance between the planes of the two groups has been reduced to one inch. The cranks are at

180 degrees and alternate cylinders are in different planes. As the crank shaft is vertical, a horizontal shaft driven through bevel gears

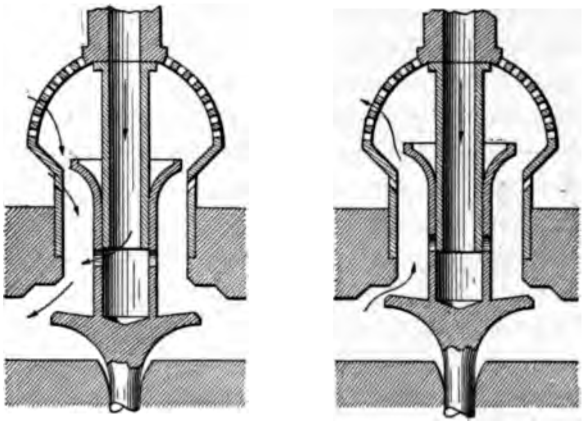


Fig. 44. Farcot Combined Valves, Inlet and Exhaust Positions

at a lower speed is provided for attaching the propeller. A combined exhaust and inlet valve similar to that of the Pipe is employed,

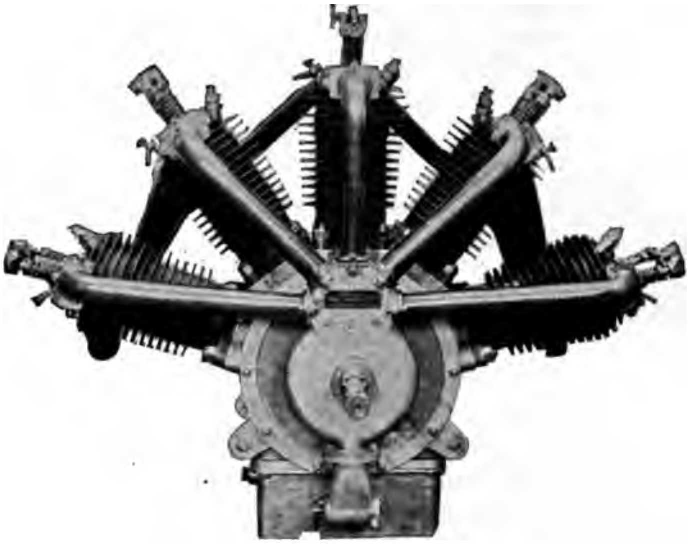


Fig. 45. R. E. P. (Pelteric) Five-Cylinder Motor

Fig. 44. Lubrication is by means of a gear pump forcing oil through the hollow crank shaft and the perforations in the latter leading up

through the connecting rods. Two small, high-tension magnetos, one set a quarter turn behind the other, provide ignition. The Farcot eight-cylinder, horizontal, circular motor is made in three sizes, 30, 50, and 100 horse-power, the weight being but 2.2 pounds per horse-power. Both magnetos weigh only 15 pounds, whereas the ordinary high-tension magneto alone weighs 25 to 30 pounds. It is claimed that the 50-horse-power Farcot motor may be made to develop as high as 70 horse-power for a short period.

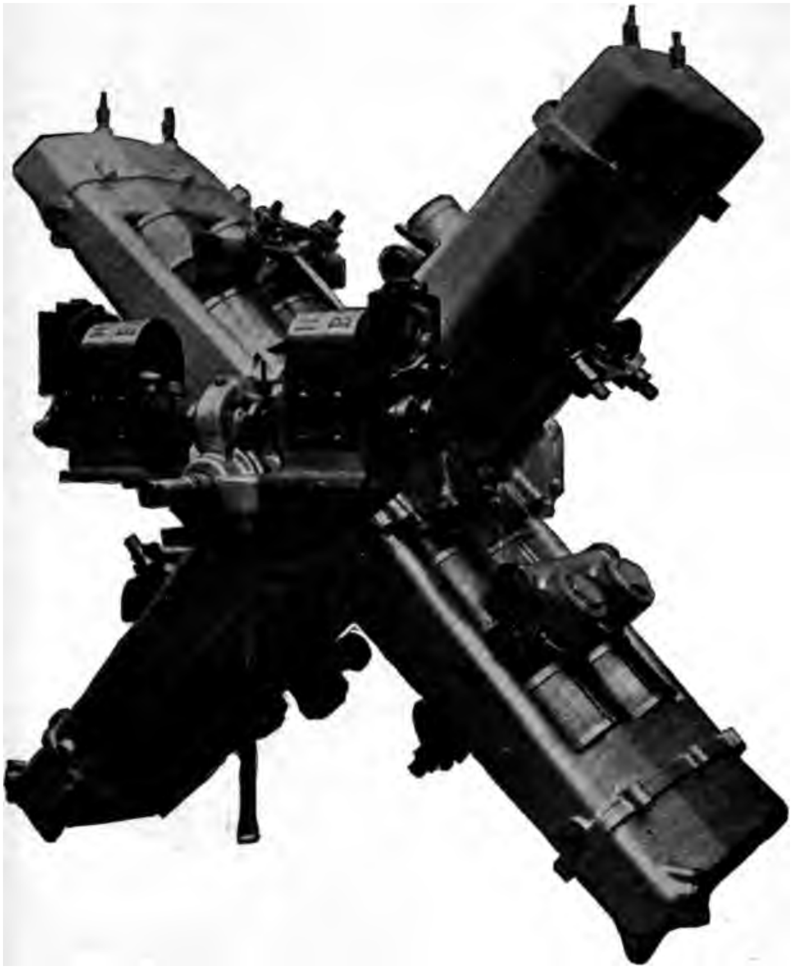


Fig. 46. Gobron-Brillé Eight-Cylinder X-Type Motor

Clement. The new Clement aeronautic motor resembles the Farcot in general arrangement, but differs considerably in detail. It has seven water-cooled cylinders, all in the same plane, the connecting rods of which are attached to a single crank. A double counterweight, acting as a flywheel, gives almost perfect balance. The normal r. p. m. rate of the motor is 1,200, but the propeller is driven at 800 r. p. m. by means of a second horizontal shaft operated through bevel gearing, as in the Farcot. The cylinders are of specially heat-treated steel, while the heads are cast steel, screw threaded and turned onto the cylinders, after which they are solidly welded in place, thus eliminating many small fastenings. The valves are in the heads and are held on their seats by small flat springs, the rocker arms having the usual helical springs. The pistons are of pressed steel, with convex heads, giving a combustion chamber whose general shape is ellipsoidal. The valves are operated by a single cam revolving in the same direction as the crank shaft and at but one-eighth its speed through gearing. There are four high points and four depressions in this large cam, corresponding, respectively, to the opening of the exhaust and inlet valves, the slow speed putting very little wear on the valve-operating mechanism, while the occurrence of the impulses regularly, two-sevenths of a revolution

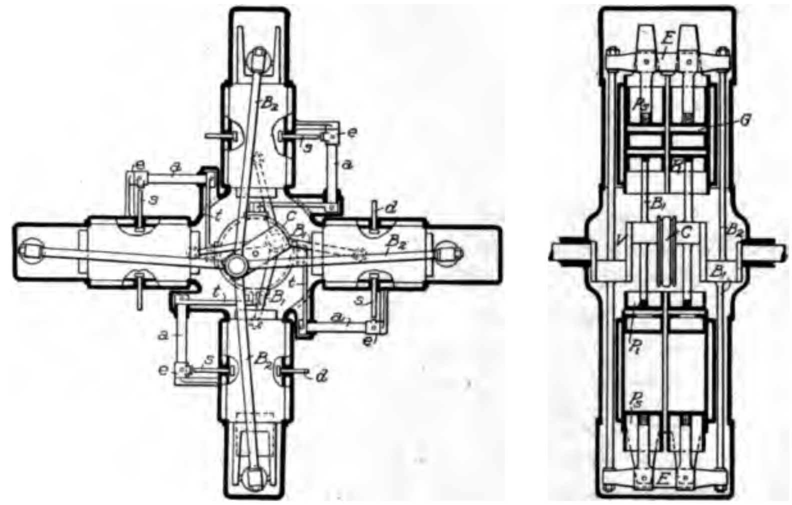


Fig. 47. Side and Edge-On Sections of Gobron-Brillé Motor

apart, gives very smooth running. There are three principal connecting rods, to which the other four are attached. These three principal rods are carried upon two sets of balls, one upon the inner two rings and the third on the intermediate pair. The crank pin is removable to permit of slipping into place the sleeve to which the connecting rods are attached. This sleeve carries the two counterweights. The high-tension magneto for ignition is driven directly from the crank shaft while a separate distributor runs at half its speed. The carbureter is located beside the crank case and connects by a short pipe to a common chamber in which all the inlet pipes terminate.


Fig. 48. Gnome Seven-Cylinder Revolving Motor

The water-circulating pump is placed about the crank shaft and forces the water directly to the bottom of the copper water jackets, which are soldered and clamped in place. The radiator of 32¼ square feet of radiating surface weighs but 26½ pounds with its tank of water. The cylinder bore is 4.3 and the stroke 4.5 inches, the motor developing 50 horse-power at 1,200 r. p. m. The diameter of the motor overall is 3 feet and its total weight in working order is only 154.3 pounds, or 3.8 pounds per horse-power. In general design and arrangement it resembles the Manley motor of 1900 built for Langley's aeroplane. The first of these Clement motors is mounted on the Clement monoplane.

Pelterie. The Pelterie (R. E. P.) is a representative fan type which attracted considerable attention by reason of its ingenious design when first placed on the market. It is built in five-, seven-, and ten-cylinder models, one of the first being shown by Fig. 45. They are of 25, 35, and 50 horse-power, respectively, the 25-horse-power model being the one illustrated. The cylinders are of the same size in all and are very small, 2.8-inch bore by 3.7-inch stroke.

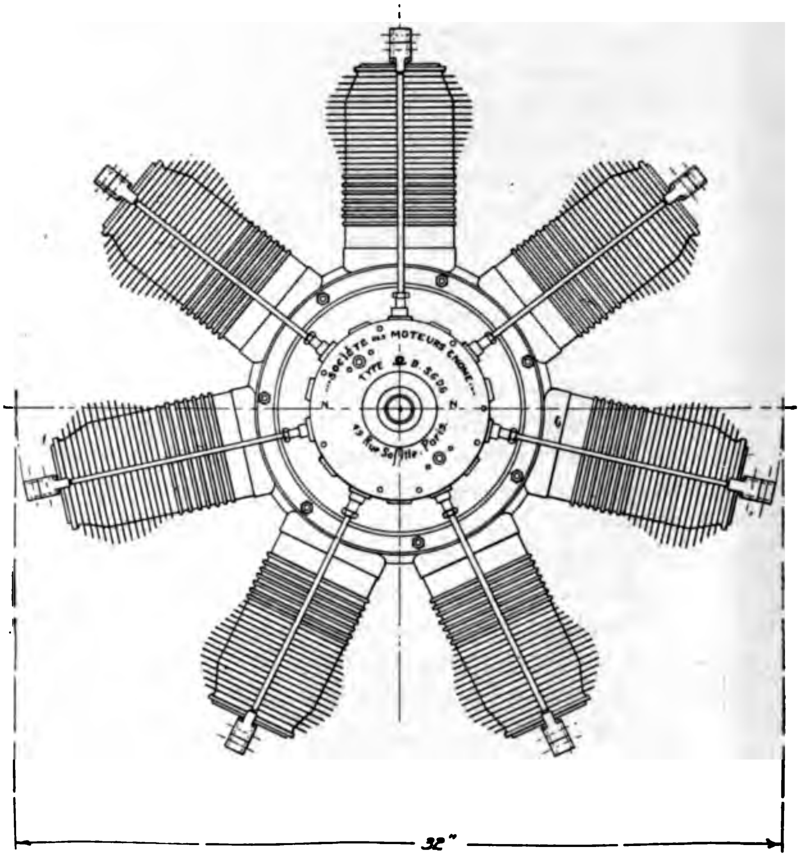


Fig. 49. Detailed Side View of Seven-Cylinder Gnome Motor

In the five-cylinder type, all the cylinders are in the same plane, while in the seven-cylinder, they are staggered, all the connecting rods being attached to a common crank pin by offsetting. The ten-cylinder motor is really two fives placed side by side and very close together. Combined inlet and exhaust valves of the form already described are employed. Two carbureters are employed on the ten-cylinder motor, with a double magneto.

Gobron-Brillé X-Form. One of the most radical departures from current practice is found in the Gobron-Brillé, Fig. 46, which has eight cylinders arranged in X-form, each cylinder having two pistons. The explosion takes place between the pistons which are thus driven apart, the connecting rods of the inner pistons being attached directly to the two-throw crank shaft in the usual manner, while the upper pistons transmit their power to the same cranks through long connecting rods passing outside of the lower pistons, but encased in a housing, so that the exhaust-valve-operating mechanism is the only moving part in view. The action of this is illustrated by Fig. 47. Above the exhaust valves of each group is placed a

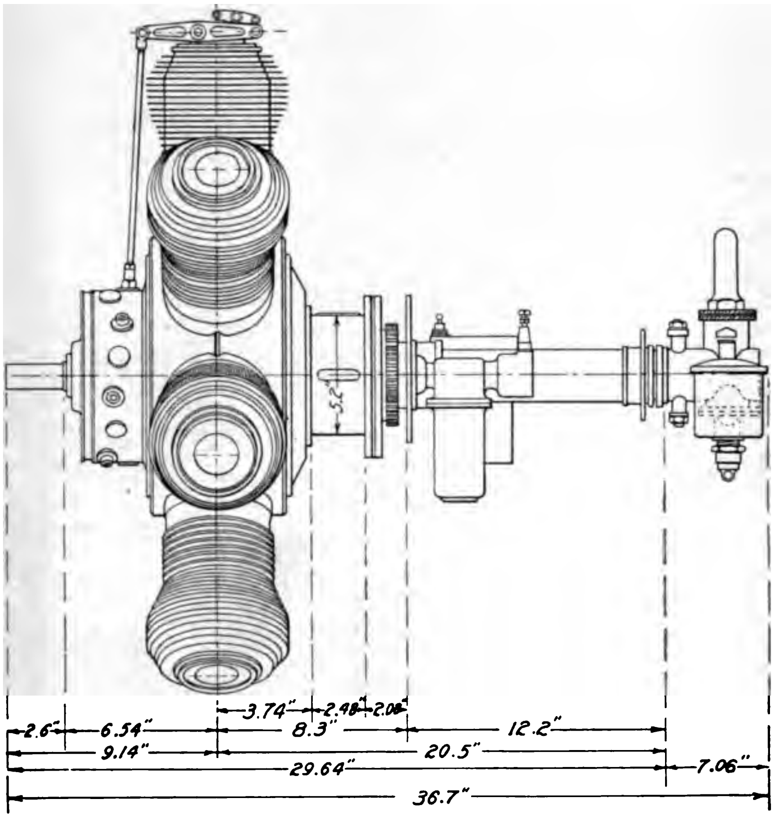


Fig. 50. End View of Seven-Cylinder Gnome Motor, Giving Dimensions

double rocker arm, which, at each turn of the shaft, opens one or the other of the two valves. To obtain the movement, each of the rocker arms *e* is fastened to a shaft *a* which is given a reciprocating movement by the lever *t*, attached to its other end. On the end of *t* is a shoe or follower, running in one or the other of the two grooves in the double cam *c*, keyed in the crank shaft. The two grooves cross at a certain point, thus switching the shoe from one to the other alternately. The inlet valves are all automatic, and are fed from a single carbureter, the inlet piping being so arranged that the course taken by the gas from the carbureter to every one of the cylinders is the same. Ignition is provided by two magnetos driv-

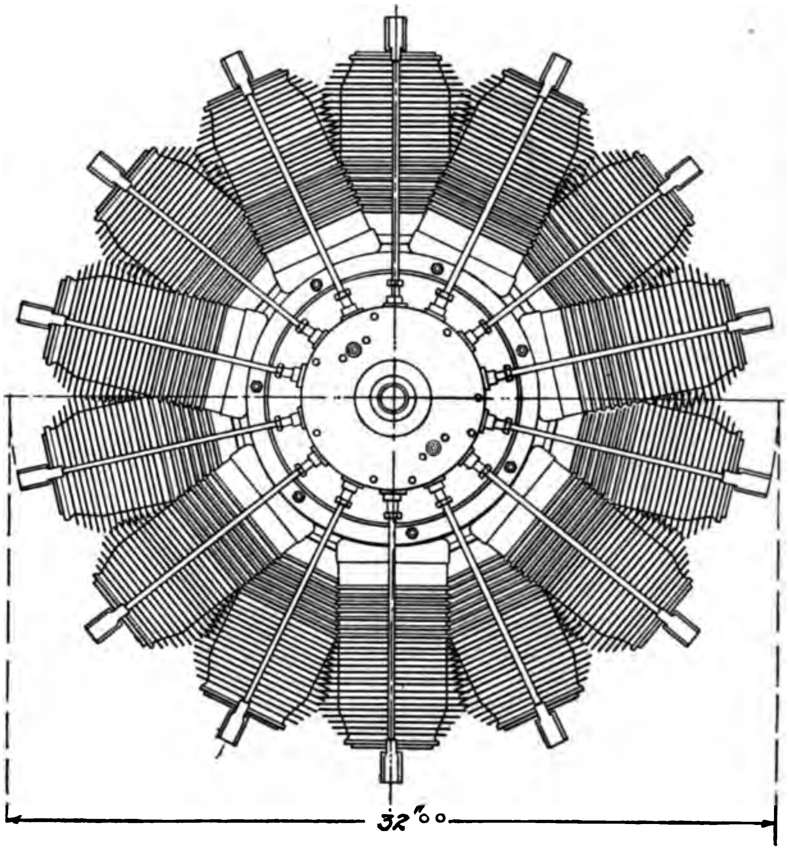


Fig. 51. Side View of Fourteen-Cylinder Gnome Motor

ing through worm gearing and a shaft at right angles to the crank shaft, the magnetos revolving in opposite directions. A gear pump forces oil to all moving parts inside the crank case, while a centrifugal pump circulates the water, of which but four gallons are necessary. It generates 75 horse-power on a total weight of 330 pounds, or 1 horse-power for every 4.4 pounds, making it one of the lightest water-cooled motors. Automobiles of the same make have been equipped with motors operating on this principle, for several years.

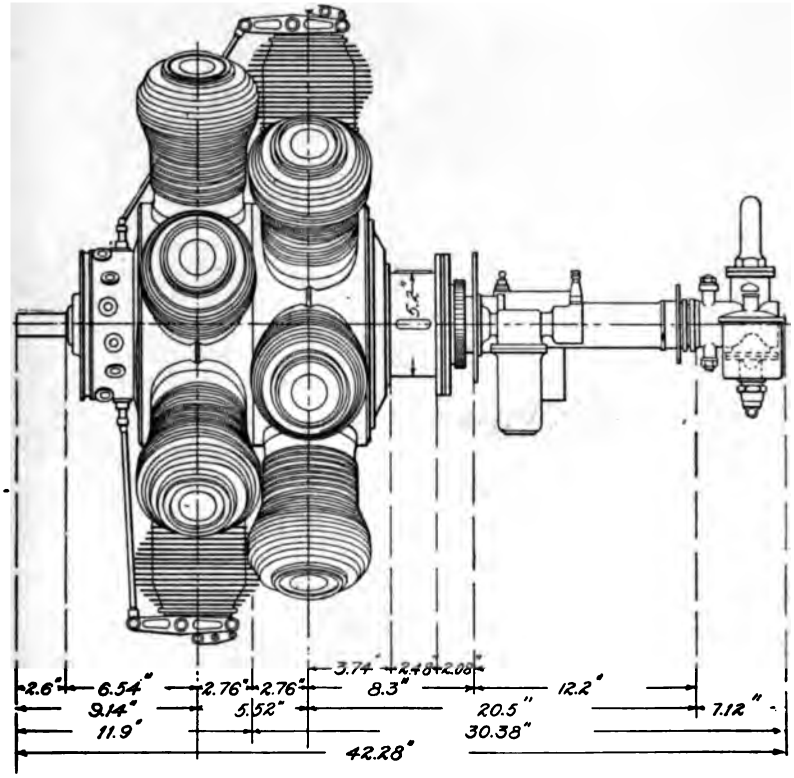


Fig. 52. End View of Fourteen-Cylinder Gnome Motor, Giving Dimensions

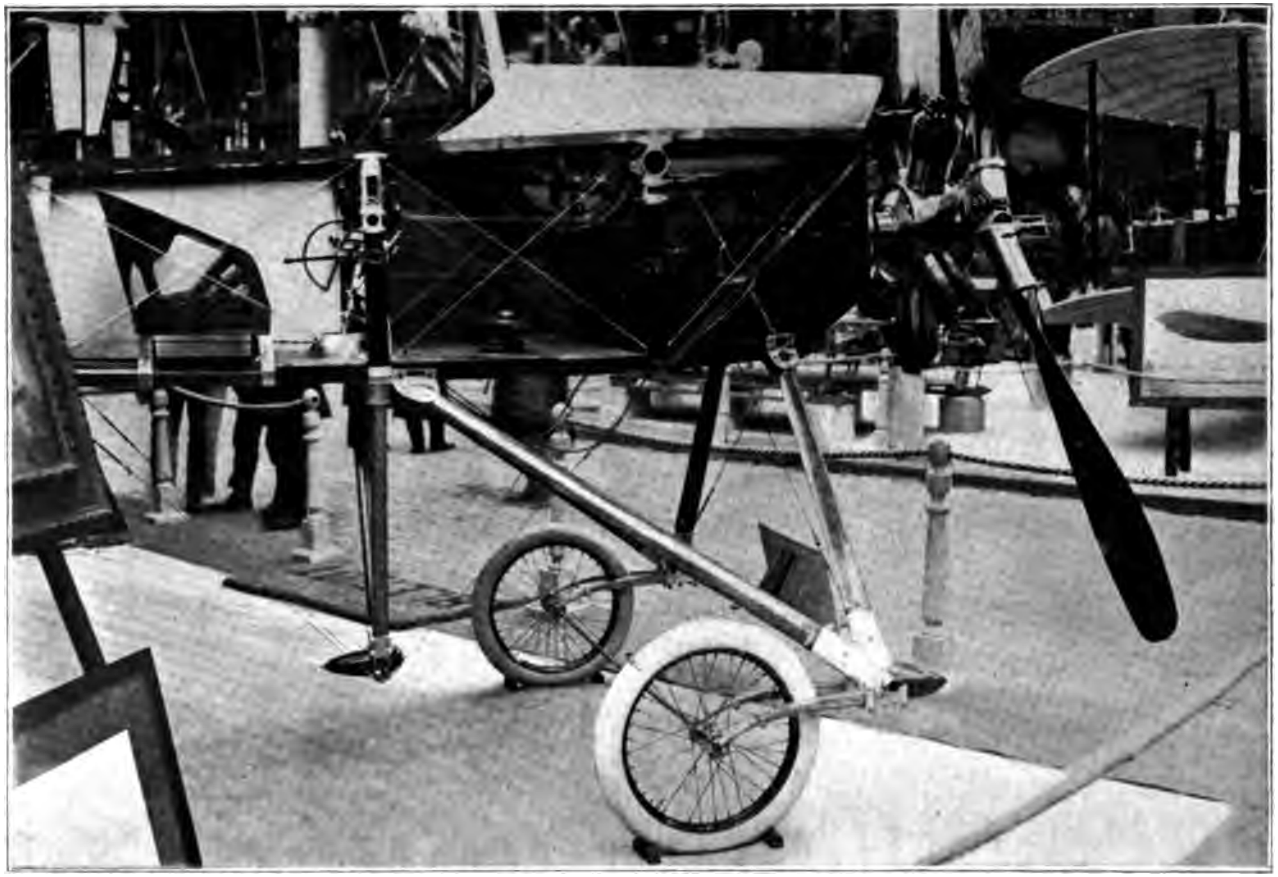
Gnome Revolving-Cylinder Type. While the revolving-cylinder motor has been known for a number of years—the Adams-Farwell (American) being one of the first successful motors of this type did not come into great prominence until 1910, and this mainly through the performance of the Gnome motor on the numerous

French machines competing at the International Meet (October, 1910). The Gnome motor is built in 50- and 100-horse-power models, the former of seven, shown in Figs. 48, 49, and 50, and the latter of fourteen cylinders—really two seven-cylinder motors, Figs. 51 and 52. The weight of the 100-horse-power model complete is 220 pounds, or 2.2 pounds per horse-power, which appears to be the minimum reached in a practical unit. The material and machine work throughout are of the very finest, the motor revolving in practically perfect balance. It is estimated, however, that the seven-cylinder motor expends at least 7 horse-power in overcoming the resistance of the air due to its revolution, the cylinders having air-cooling flanges which taper broadly near the heads, thus presenting considerable surface. The cylinders are mounted symmetrically about a drum-shaped crank case, as in the Clement, and have large exhaust valves placed in the heads and operated by rocker arms. The inlet valves are placed in the heads of the pistons and are automatic so that centrifugal force is taken advantage of to draw in the fuel as well as to expel the burnt gases through the exhaust valves. Both valves are counter-weighted to neutralize this force. The bore is about 4.4 inches and the stroke 4.8 inches, all seven connecting rods being attached to a common crank pin, or to a two-throw crank pin in the fourteen-cylinder type, *i. e.*, one rod acts on the pin and the others are articulated to it. Fuel is admitted to the crank case through the hollow crank shaft to one end of which the carbureter is directly attached, while lubricating oil is injected in the same manner by means of a two-cylinder reciprocating pump, with two distributors.

An improved model of the seven-cylinder Gnome was brought out during 1911. This is rated at 70 horse-power and the first of this type completed was brought to the United States by Earle Ovington on his new Bleriot monoplane with the "inverse curve" form of tail. It requires a skilled mechanic, thoroughly familiar with the Gnome construction, to dismount the 50-horse-power model, but in the new 70-horse-power model it is only necessary to remove a few nuts to take off the front half of the crank case, leaving the cylinders readily detachable, while the method of clamping them has also been made much more secure. The receptacles into which the spark plugs are screwed are internally threaded steel tubes welded into the side of the cylinder by a secret process, while the automatic inlet valves, balanced by counterweights to offset the action of centrifugal force, are made so that they can be withdrawn through the cylinder heads, making it unnecessary to take down the engine for this purpose. It was with one of the new 70-horse-power Gnome motors that Weyman won the 1911 Gordon-Bennett in a Nieuport monoplane.

As the motor revolves at 1,300 r. p. m. normally, the centrifugal force is terrific and the oil is practically pumped right through the motor—or, in other words, pumped in and thrown out. Castor oil is employed for the purpose and the consumption is very great—at least half a gallon of lubricant being necessary for every gallon of gasoline used. The consumption of fuel is also very high—300 grammes per horse-power hour—about 10.6 ounces of gasoline, or about 44.1 pounds per hour for the 50-horse-power motor and close to 90 pounds per hour for the 100-horse-power motor, which, with lubricant, would make 100 pounds of gasoline and oil to run the larger motor one hour. This extravagant consumption of fuel and oil, particularly such high-priced lubricant as castor oil, is the chief drawback of the revolving-cylinder motor, and the latter will undoubtedly have to be improved in this respect if it is to maintain its lead.

More than 500 Gnome revolving motors have been built and it has to its credit almost every world's record for 1910 except that of altitude (Wright), and including such events as the Gordon-Bennett Cup, London to Manchester, Paris-London, Crossing the Alps, Statue of Liberty, *Circuit de L'Est*, and other important speed, as well as altitude, and endurance flights, more than $500,000 in prize money having been won during 1910 alone in machines equipped with Gnome motors.



UNIQUE VIEW OF THE BLERIOT "TYPE POPULAIRE" WITH ONE WING AND ONE SIDE OF BODY REMOVED
SHOWING THE INTERIOR ACCOMMODATION AND MECHANISM

AERIAL PROPELLER

Volumes have been written on the theory and design of the screw propeller as applied to marine practice, yet after so many years of actual use there are still many things that remain to be definitely settled. A change in the condition of operations renders previous data of little value, as in the case of the adoption of the high-speed turbine for marine propulsion, the "Mauretania" having been equipped with no fewer than three different sets of screws since she was first put in service. It is, accordingly, not to be greatly wondered at that there should be a conflict of opinion where the aerial propeller is concerned. Obviously, the propeller is no less important an essential than the planes themselves, for support in an aeroplane is entirely dependent upon speed. To obtain speed, thrust is necessary, and it is the function of the propeller to produce it. How this may be done most efficiently is the object of an endless amount of research that is being carried on at the present time. The purpose of the present subject is to reflect current practice—to give as far as possible the data upon which the designs of the most successful propellers are based, to show how the propellers themselves are made, and why they are so made, as drawn from actual experience rather than from purely theoretical ideas.

In view of the imperfect engineering knowledge extant on the subject at this late day, it appears rather marvelous that the scientist-philosopher Leonardo da Vinci should have proposed the use of the propeller in one of the aerial navigation schemes which came up in his day—more than four hundred years ago. Of course, the propeller as it exists today was not known then, but the screw principle upon which it is based is centuries old. In fact, General Meusnier's conception of the *turning oars* in his plan for a dirigible balloon antedates the actual use of the propeller for marine service by many years, and was likewise a strikingly approximate anticipation of the aerial propeller of the present day.

Factors in Propeller Action. *Pitch.* Before taking up the design or construction, the essential features of a propeller should be considered in order that the technical terms referring to them may be intelligible. As its name indicates the *screw propeller* is based upon the principle of the screw thread. Pitch in a propeller is exactly the same thing as the pitch of a screw thread, in other words, the distance traversed by the thread along the screw in one complete revolution. When a nut is turned on or off a bolt, it moves a certain distance along the bolt for each turn, and this distance is its pitch. It can not move more or less because its movement is confined to the thread. But with reference to a propeller, Fig. 1, this distance is a purely theoretical measurement, as the substance upon which it acts is yielding, whether air or water. However, as the laws relating to fluids are, for the most part, applicable to all fluids, whether liquid or gaseous, advantage has been taken of the accumulated knowledge of marine engineering, to discover the best means for designing propellers for the aeroplane.

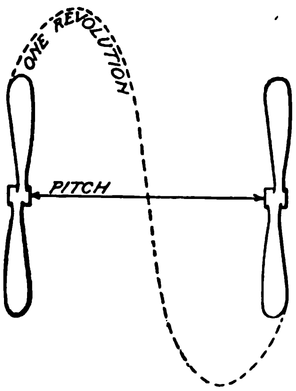


Fig. 1. Diagram Showing Pitch of a Propeller

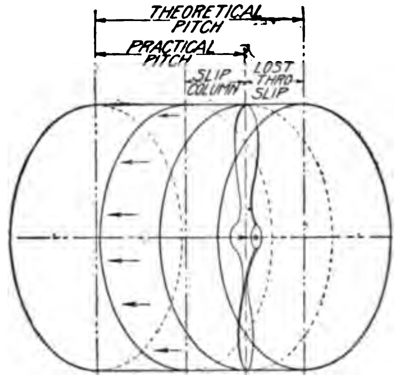


Fig. 2. Diagram Showing Correction for Slip

Slip. It is a fact that a propeller in water does not practically advance the distance, or propel the vessel to which it is attached, the distance represented by its pitch. The difference between this and the actual result obtained is designated by the term "slip." (See Fig. 2.) As slip represents lost energy and a propeller with a high percentage of slip would be very inefficient, it would appear to be desirable to reduce this factor to the minimum. However, this is not the case. If there were no slip, there could be no reaction on the volume of air or water being driven backward by the propeller, and there would consequently be no thrust, so that if the slip be reduced too far, the propeller would again be inefficient. At any rate, such is the conclusion drawn from marine practice, where it is customary to regard a slip of 10 to 20 per cent, *i. e.*, an efficiency of 80 to 90 per cent, as being representative of the most economical results obtainable. In the case of the aerial propeller, slip up to 25 per cent is considered good, 40 per cent bad, and about 15 per cent the most economical.

Aside from the diameter the element on which the friction losses depend almost entirely, is the *pitch.* Aeroplane propellers fastened directly to the crank shaft of the motor must of necessity have a smaller pitch, while those driven by intermediate gearing or chains and sprockets may be given a large pitch when desired. The motor must run at a high speed in order to develop its power without excessive weight, and if a propeller of large pitch be secured directly to the shaft, it would offer so much resistance that the motor would not reach its normal speed. The usual speed of aeronautic motors is around 1,200 r. p. m. If the aeroplane makes a speed of 40 miles an hour the pitch of the direct-connected propeller will be from 3½ to 5 feet, while on a machine like the Wright biplane, the propeller turns at 450 r. p. m. and the pitch is nearer 10 feet.

The friction and head resistance of the propeller blades passing through the air vary approximately as the square of the velocity. If the two propellers each had a diameter of 8 feet, the mean velocity of the blades of the small pitch propeller, through the air, would be about 2.8 times as great as that of the large pitch propeller, and the loss of power resulting from friction and head resistance would be about eight times as great. For this reason, it is desirable to make the pitch large and keep down the revolutions as compared with speed. On the other hand, if the pitch be made too large, the air is pushed around sidewise instead of being pushed to the rear, and as such motion of the air does not produce thrust, excessive power is lost in that manner. With air propellers, as with marine propellers, it has been found that the best pitch is from 1.2 to 1.5 times the diameter. There is also a practical disadvantage in making the pitch too large, and this is, that the starting thrust, before the aeroplane has got up to speed, is considerably less than with finer pitch propellers.

Thrust. Thrust is work done by the propeller in moving the aeroplane, and is equal to the weight of the mass of air acted on per second times the slip velocity in feet per second. This is *dynamic thrust*. The effort of the same propeller on the column of air in which it acts when standing still, is termed *static thrust*. An illustration of the difference between the two may be drawn from the starting of an aeroplane from the ground. While held prior to running over the ground, the screw is exerting static thrust. The moment the machine is released, it begins to exert dynamic thrust in that it is then forcing the aeroplane ahead. It is generally conceded that the amount of static thrust a certain propeller is to exert affords no definite measurement of what it is capable of doing when driving the machine through the air, or rather that its static thrust will be much greater than its dynamic, although Sir Hiram Maxim states that, as the result of his experiments, both were found to be the same. The thrust of the propeller in question was said not to vary whether it was traveling through the air at a velocity of 40 miles an hour, or standing stationary, the r. p. m. rate of the motor remaining constant. The explanation is that when traveling, the propeller is constantly advancing on to undisturbed air and that while the slip velocity is reduced, the undisturbed air is equivalent to acting upon a greater mass.

The factors affecting the thrust given by a propeller are: *First*, the diameter, blade area, and pitch or blade angle, which may be termed propeller characteristics; *second*, the speed of revolution, which is proportionate to the engine driving power; and *third*, the rate at which the characteristics of the vessel will allow the propeller to move through the fluid. The propeller which is the most efficient is naturally the one which will produce the greatest amount of thrust in proportion to the power transmitted it by the engine, both when revolving in a fixed position on the ground and when traveling through the air. Each of the factors mentioned must be provided for in the design. A propeller which is too large or of too great a pitch for a given motor, will effectually prevent the motor from developing its normal power by retarding the r. p. m. rate. Propeller blades that are not given sufficient area or pitch will permit the engine to race through not imposing sufficient load on it, and if the speed becomes greatly excessive, the blades are likely to burst or fly apart through centrifugal force. Should the engine be too powerful for the propeller, the blades may bend and break under the strain.

Pitch Ratio. Another characteristic having an important bearing on the result is the *pitch coefficient*, or *pitch ratio*, as it is frequently termed. There is a certain analogy between the propeller and the main planes in that both are intended to drive through the air easily and at the same time exert a sufficient hold on the air either for the purpose of support, as in the latter instance, or for driving, as in the former. Pitch ratio is consequently analogous to aspect ratio. It is the ratio that the pitch bears to the diameter, or length of the propeller. The pitch coefficients of eighteen well-known monoplanes and biplanes vary from 0.4 to 0.2, the mean value being 0.62, which, as it so happens, is exactly that of the Farman propeller. The pitch ratio of the Wright propeller is said to be 1, and its unusually high efficiency is generally conceded, though very few builders have apparently considered it expedient to adopt the means that make this efficiency possible, *i.e.*, propellers of large pitch and diameter turning at the very slow speed of 450 r. p. m. The propeller of the Bleriot XI has a pitch ratio of 0.4, but it is designed to run at 1,350 r. p. m.

Diameter. The diameter is affected by structural considerations, the placing of the motor and other conditions, which restrict the size of propeller that can be employed on a certain machine. Different experimenters have widely-differing standards in this respect, as witness the use of 4-foot extremely high-speed propellers on some machines and 8-foot slow-speed propellers on others. The disadvantage of using a very small propeller is now generally recognized, however, and few, if any, of less than 6-foot diameter are employed. The question of efficiency is so largely dependent upon the diameter, that we may look for an *increase* rather than a *decrease* in the machines of the future. In fact, the whole question of the efficiency of the 2-bladed aerial propeller seems to be one of *diameter* and *speed.* Speaking in general of properly-designed concave propellers, a propeller of large size and slow speed is always more efficient, all other things being equal. Reduce the diameter and increase the speed and the efficiency drops off very rapidly—from as high as 50 pounds thrust per horse-power to as low as 6 pounds per horse-power, these figures being the result of experiments carried out especially to establish the effect of altering the relation of these two essentials of design. The falling off in the efficiency at high speeds is remarkable, for while it seems possible with the best designs to obtain as high as 40 to 50 pounds thrust per horse-power, the average modern aeroplane has a screw of one-sixth this efficiency, or about 7 pounds per horse-power.

Peripheral Speed. The limiting factor in the propeller is its peripheral rather than its rotational speed, since it is upon this that the centrifugal stresses, which are by far the most severe of all involved, depend. The propellers of practically all aeroplanes built so far run at peripheral speeds ranging from 12,000 to 40,000 feet per minute, with occasional instances of speeds as high as 50,000 feet per minute, the rotational speeds being so adjusted to the diameters of the propellers as to produce little variation outside of the range given. At the higher of the speeds mentioned, nearly 570 miles per hour, centrifugal force is so great as to test to its utmost the quality of the finest structural material obtainable.

That it is better to gain permissible peripheral speeds by the use of large diameter propellers at low-rotational speeds, rather than with small propellers at high-rotational speeds, becomes very evident with a little study. Take, for example, the case of a portion of a propeller surface, 1 foot long and 1 foot wide, traveling edgewise round a 30-foot circumference, 600 times a minute, it being assumed that a peripheral speed of 18,000 feet per minute is the maximum permissible in the case in question. Under the conditions stated, the surface passes any given point 10 times per second—often enough to produce a material disturbance of the air worked against. Now assume the circumference reduced to 15 feet by a corresponding halving of the propeller diameter, and immediately it becomes apparent that a doubling of the rotational speed is allowed without increasing the peripheral speed.

But, under the new conditions, the assumed propeller surface passes any given point 20 times per second, twice as often as before with a correspondingly reduced assurance of finding undisturbed air to work against. Moreover, since the blade surface travels the same distance in the same time in both cases, there is no opportunity to reduce its area on account of the higher rotational speed in the smaller propeller. The result is that the blade which is of a width only $\frac{1}{30}$ the length of its path in the large propeller, is in the smaller one $\frac{1}{15}$ its length—a condition that operates directly against maximum effectiveness. Of course, it may be urged that when a propeller is traveling through the air under its normal condition of operation, instead of revolving in a circle, as when kept from advancing, the blades travel separate helical paths, wholly distinct from one another. But these paths are, nevertheless, closely adjacent and become more so with every increase in the number of blades and every decrease in the pitch. From these considerations, it will be evident that large diameters and a minimum number of blades reduce the frequency of the air disturbance and tend to eliminate interference. The largest propeller built thus far, to the writer's knowledge, was turned out in the fall of 1910 for a monster 2,200-pound aeroplane at that time building in California. This propeller measured 14½ feet in diameter, with a corresponding coarse pitch, as compared with the 6- to 8-foot propellers commonly employed.

The air acted on by the propeller is limited to that which flows through the circle described by the tips of the blades, frequently referred to as the *disk*, Fig. 3. The amount acted upon, therefore, increases with the diameter, and as the thrust depends directly upon the volume of air and the velocity at which it is displaced to the rear, it follows that the greater the diameter the less the rearward velocity need be to obtain a given thrust. Thus approximately the same thrust will be obtained from an 8-foot propeller which imparts a 5-mile velocity to the air, as from a 4-foot propeller that imparts a 20-mile velocity. It is self-evident that of the total power developed by the motor only a part is actually utilized in forcing the machine ahead through the air—the remainder does no useful work and is lost. A considerable portion of this lost energy is contained in the air which has been pushed to the rear by the propeller. The amount of such lost power increases as the square of the velocity at which it is pushed astern. In the 4-foot and 8-foot propellers compared above, it is found that when developing the same thrust at a speed of 40 miles per hour, the amount of lost power in the case of the smaller one is about three times as great as in that of the larger one. This is the underlying

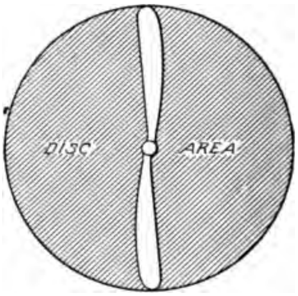


Fig. 3. Diagram Showing Effective Area of Propeller Influence

reason why small propellers are inefficient when used to develop relatively high thrust.

Power of Propellers. To obtain thrust from a propeller, it must waste some power, for reasons that have already been mentioned —it is essential to thrust some air at least to the rear. The smallest quantity that it is necessary to waste can be figured out, and this added to the useful power gives the minimum amount of power which would be required with a perfect and frictionless propeller.

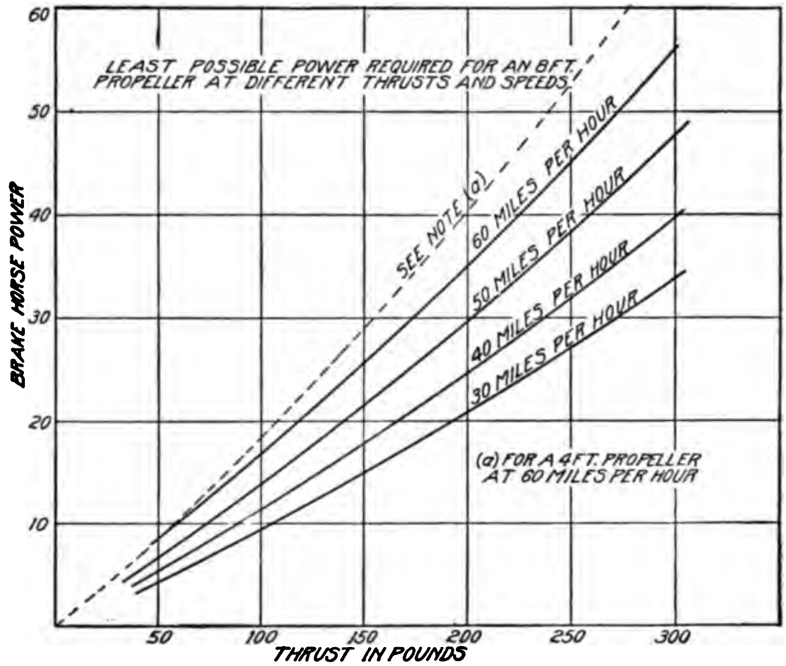


Fig 4. Minimum Power Required for 8-Foot Propeller at Various Thrusts and Speeds

The curves in Fig. 4 show this least power for an 8-foot propeller at different thrusts and at speeds of from 30 to 60 miles an hour. As a matter of fact, no propeller can be expected to reach the theoretical limit. Many of the best air propellers require about 25 per cent more power than that shown by the curves in Fig. 4, and in fact, the curves in Fig. 5, which show the power which will be needed for a good type of propeller, have been prepared by adding 25 per cent to the theoretical power required in each case. For example, from the curves in Fig. 5, at a speed of 40 miles, a thrust of 100 pounds should be obtained with 14.7 brake horse-power. The Wright Brothers obtain this thrust with about 15 horse-power, which agrees practically with the above.

In Fig. 4, the dotted line shows the minimum power theoretically necessary for a 4-foot propeller at a speed of 60 miles and at

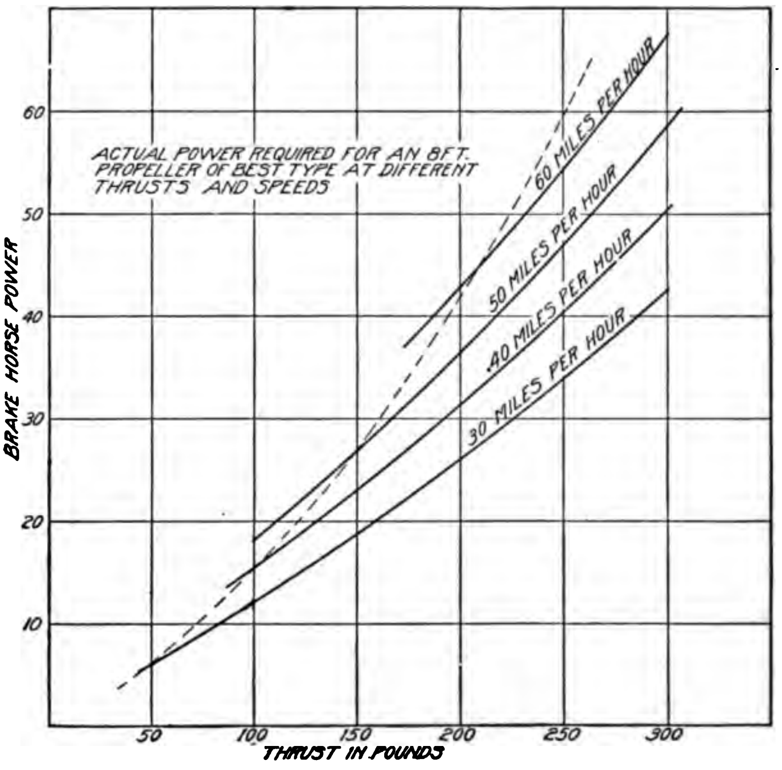


Fig. 5. Actual Power Required for 8-Foot Propeller at Various Thrusts and Speeds

different thrusts. At a thrust of 200 pounds, 41 horse-power is necessary, while for an 8-foot propeller only 35 horse-power is required. That is, at this speed and thrust, the smaller propeller requires 20 per cent more power than the larger one.

This particular compromise of using a small-diameter, high-speed screw to suit the rest of the design has cost the present-day aeroplane an enormous toll. It makes it necessary to carry a motor several times more powerful and heavy than it should be, with a consequent increase in the size of the aeroplane itself in order to carry the extra weight. The large-diameter, slow-speed screws of the Wright machines are undoubtedly the chief basis of the unusually high efficiency that they show. Langley demonstrated that 1 horse-power, properly applied, could carry 200 pounds at 40 miles per hour. But what machine approaches this? On the same basis, the Wright machine should theoretically be able to fly with a 7-horse-power motor, 2 horse-power being allowed for overcoming the resistance of the non-supporting surfaces, such as the struts, guy wires, and the like, while 5 horse-power would be all that is needed to drive it through the air at its usual speed. But this would entail propellers of great diameter, turning at a slow speed, and they are not compatible with the rest of the design. If they were, it seems that a tremendous saving could be effected; the weight of the engine could be greatly reduced and the radius of action of the machine increased at least threefold.

If allowance be made for the difference in the weights of a cubic foot of water and a cubic foot of air, and the speed is changed from knots to miles per hour, the corresponding formula for air propellers is

$$d=\frac{33\sqrt{T}}{V}$$

For a thrust of 100 pounds and a speed of 40 miles per hour, the diameter would be

$$d=\frac{33\times\sqrt{100}}{40}=8\tfrac{1}{4}\text{ feet}$$

This agrees in practice with the results obtained by the Wright Brothers, who use an $8\frac{1}{2}$-foot propeller for this thrust and speed. The dotted line in Fig. 5 shows this relation for an 8-foot propeller. The line crosses the power curve for a speed of 60 miles at a thrust of 210 pounds, and that should be the thrust of about the best efficiency. At a speed of 40 miles the best efficiency would be obtained with a thrust of about 95 pounds.

From the above it appears that the larger the diameter the better, and this would be true but for friction and head resistance of the air to the propeller blades. This increases as the diameter is increased, and the power lost from this cause soon becomes as great or greater than that carried away by the air in the propeller race or wake. With other conditions equal and developing the same thrust, an 8-foot propeller will lose from frictional and head resistance about twice as much power as a 4-foot propeller. This makes it apparent that the relation between the diameter, speed, and thrust is an important one. If the diameter is small, there is excessive loss of power in the propeller race, while if too large, the frictional losses are very high, so that a compromise is necessary. In water it has been found that when cavitation does not occur, the most effective diameter is given by the formula

$$d=\frac{\sqrt{T}}{V}$$

where d is the diameter in feet, T the thrust in pounds, and V the speed of the vessel in knots.

Propeller Blades. The next characteristic is the blade. Leonardo's propeller was a screw or helix of a single *worm* or *thread*—being practically all *worm*, and constituting an entire convolution, of which the modern equivalent would be a single-bladed screw, blades being a much later development. It is easy to realize how the original screw propeller came to be of the single *worm* type, and why one complete turn was deemed essential. It was first discovered by actual experiment that half a convolution was fully as efficient as a whole turn, then that a quarter turn was more efficient than half, but with this curtailing of the helix a formidable difficulty arose. It had now developed into a 1-bladed screw, was unsymmetrical and consequently unbalanced. Centrifugal force and 1-sided thrust now jointly interposed with inimical results. It finally appeared that to produce a more efficient, compact, and symmetrical screw propeller, while employing only a fraction of a convolution, two or more *worms* were necessary—in other words, blades. Thus it gradually came to pass that the modern aerial true-screw propeller is but a very short length cut off a 2-threaded screw, in which the thread is relatively deep, with a pitch equal to about two-thirds its diameter. A marked later tendency was to err on the side of plurality of blades, and this was still in evidence when propellers first came to be used for aerial propulsion.

Thus the Ericsson marine propeller was formed of a short section of a 12-thread screw of very coarse pitch and naturally proved very inefficient. The aerial fan propeller of Moy had six broad vanes enclosed within a hoop, and was not a screw at all. It was little better. The same remarks apply to the propellers of Henson, Stringfellow, Linfield, du Temple, and many others. Even the first propeller fans used by Professor Langley were 6-bladed, though in his subsequent and highly successful aerodrome, the twin propellers were 2-bladed true screws, as were also those of the Maxim machine. The latter afforded striking evidence of the efficiency of large-diameter, slow-speed propellers.

Number: Theoretically, the number of blades need not be considered at all. The mass of air dealt with by the propeller is represented by a cylinder of indefinite length, the diameter of which is the same as that of the screw, and the rate at which this cylinder is projected to the rear, depends theoretically upon the pitch and the number of turns per minute of the propeller, and not upon the number of blades, one or an incomplete helix being sufficient, except for mechanical reasons. The minimum number which can be employed practically is, therefore, two—and experience has demonstrated that the same number represents the practical maximum for an aerial propeller. The function of the latter is to create *thrust,* and to do this, it must force the air to the rear with the least possible *internal disturbance, i. e.,* it should be thrust backward as a clean-cut cylinder, and not as a whirling, tumbling mass, which would tend to set up a dragging wake and interfere with the efficiency of the propeller and the speed of the machine. Any number of blades in excess of two could not operate in undisturbed air and would, in consequence, simply act to churn the mass already set in motion by the others. Except in case of very small propellers, three blades are ordinarily employed in marine practice so as to give better mechanical balance.

It may seem strange at first sight that a ventilating fan should operate most efficiently with a large number of blades set close together and with a fine pitch, while the opposite extreme is necessary for an aerial propeller. Stand in the blast of a big ventilating fan and it appears to set up a powerful current of air which should represent the equivalent of considerable thrust. It does, but it must be borne in mind that a ventilating fan and a propeller are two totally different things. Because many blades are found to be most efficient in the case of the former, it is wholly wrong to assume that the same conclusion holds good in the case of the latter. By increasing the number of blades, the skin friction due to the resistance that has to be overcome in rotating the propeller through the air is augmented. Moreover, a fan is stationary, while a propeller is constantly advancing as well as rotating through the air. The action of a fan blower is to move a small quantity of air at a high velocity, whereas the action of a propeller is, or should be, to move a large quantity of air at a low velocity, since the function of the screw is to create thrust. Operating on a yielding fluid medium this thrust will evidently be in proportion to the mass of fluid moved, and also to the velocity at which it is put in motion. But the power consumed in putting this mass of air in motion is proportional to the extent of the mass and to the square of the velocity at which it moves. From this, it follows that to obtain a given thrust with a certain amount of power, it is essential that as large a volume of air be handled as possible and that the velocity imparted to it be as little as possible. As explained in connection with the action of the propeller when the aeroplane is held and when in flight, the fan is designed to create static thrust while the propeller is designed to set up dynamic thrust. The maximum volume of air must be moved backward with the least possible acceleration. In fact, the multi-bladed propeller revolving at a high speed is apt to set up what is known in marine engineering parlance as "cavitation," in which the high speed of the screw causes it to carry round a certain amount of the medium with it, so that the blades strike no undisturbed or *solid* air at all with a proportionate decrease in thrust, or rather an almost entire absence of it. The propeller literally "digs a hole in the air" and revolves in it without pushing the aeroplane ahead.

It will also be evident that there is possible a number of blade arrangements. Not only may the blades differ in their number, in their outline, in their cross section, pitch, and angles of setting, but they may also differ in the angles they make with their plane of rotation, in their longitudinal placing on the propeller shaft, and in the use of longitudinal sections from hub to tip that are straight or curved. Propeller blades in line, or at right angles to the shaft, are almost universal. The advantage of this is that centrifugal force exerts a direct pull from the hub without any tendency to move the blades longitudinally, parallel with the axis of revolution. A supposed disadvantage is the escape of air from the propeller tips without aiding in propulsion. But as any such rapidly thrown air is more apparent when the propeller is held and is then working as a fan, than when working in flight, it has never been considered of sufficient seriousness to be taken into consideration.

Dihedrally-arranged propeller blades with the hub forward, either with straight or curved blades, would utilize the air that is apt to escape at the tips, but they would also increase the amount of the disturbance, subjecting the air behind the blades to direct centrifugal action. Moreover, this would require very stiff blades or guy wires, to prevent the blades from straightening out under centrifugal force, and such wires would interpose additional resistance to rotation with a corresponding disadvantage.

Area. This violent disturbance of the air is affected very markedly by the area of the blades. In marine engineering, narrow blades are usually employed on slow-speed propellers where cavitation is not a factor to be guarded against. But in high-speed marine propellers, where it is likely to occur, the projected area of the blades is sometimes as much as 0.6 of the total disk area. In the case of aerial propellers, cavitation is not likely to occur, particularly with a 2-bladed propeller, unless the speed is very high—1,500 r. p. m. or more, so that narrow blades are preferable. Experiments in marine propulsion also show that the thrust depends more upon the disk area than upon the width of the blades. Both in marine and aerial practice, multiplicity of blades, or increased blade area; tends to reduce the efficiency, apart altogether from the questions of weight and constructional difficulties.

Contour. It must be borne in mind that a propeller is nothing more nor less than a form of aeroplane specially designed to travel a helical path, and that the same laws govern it as those pertaining to the action of the supporting surfaces in striking and passing through the air which forms their support. The blades should, therefore, be *concave* or *hollow-faced* and partake of the *stream line* formation, a condition that is not fulfilled where the face of the blade is flat, such a surface cutting into the air with considerable shock, and by no means creating as little undesirable motion in the surrounding medium as possible. A curved face blade has of necessity an increasing pitch from the cutting edge, or attacking face, to the trailing edge (considering, of course, any particular section). In such a case, the pitch of the propeller is its mean effective pitch. This question of increasing pitch with the width of the blade, has an important bearing on the subject of blade area, as to make a wide hollow-faced blade would soon result in reaching an excessive angle. In the case of the flat blade, the same thing is true, because by the contact of its molecules with the "initial minimum width" the air has already been accelerated up to its final velocity, and further area is not alone wasted, but is detrimental to efficiency. Requisite strength and stiffness, of course, set a limit on the final narrowness of the blades, apart from other considerations.

Flexible Type. Reference has been confined to propellers with rigid blades—preferably of wood. There is another type, known as the flexible-bladed propeller, which is so constructed as to give a self-feathering action to the blades, *i.e.*, a self-varying pitch, the air resistance to rotation causing the blades to twist, and to become of less and less pitch with increasing speed. This type has found some advocates, or at least it did three or four years ago. Experiments with it indicate a great loss of power, so that it is far from efficient. A flexible-bladed type of this kind measuring 19 inches in diameter and having three blades showed on test a thrust of only 3 ounces at 480 r. p. m. The power was estimated at about $\frac{1}{8}$-horse-power, which would give a result of 1 pound thrust per horse-power, so that it seems hardly worth while to experiment further with this type.

Fabric-Covered. Another form of propeller that has been used consists of a frame, over which canvas is stretched taut to form the blades, but the fabric does not remain taut when the propeller is revolving at a high speed. It is, moreover, difficult to make anything but a flat-bladed propeller in this form and have it sufficiently rigid. Such propellers were employed on some of the early French dirigibles, mainly on account of their lightness, but they did not prove practical.

Another disadvantage of these fabric propellers was the fact that the blades consisted of only comparatively small, isolated surfaces at the outer ends of the supporting arms, and this fault was repeated in some of the metal propellers employed abroad. This has been done on the ground that the part of the blade near the hub adds little or nothing to the effective thrust of the propeller. While this is undoubtedly true, every part of the blade, except where it actually loses its curvature to become part of the hub, exerts its proportionate amount of propulsive power, whereas in the other type, resembling a double canoe paddle, the cut away part merely adds to the air resistance of the machine as a whole, and the efficiency of the screw itself is reduced proportionately. Variable pitch propellers for aeroplanes have again been taken up in France notably by Brequet and Antoinette, but the blades have been of wood or metal, mounted so as to permit of partially revolving on their own axis, this movement being controlled by springs.

Speaking of efficiency, it will be noted that the best results obtained by some of the earlier experimenters were not very high. The thrust per brake horse-power obtained by Langley was 7 pounds, by Maxim 9 pounds, by Spencer, using a Maxim-type propeller, 6 pounds, by Farman and a number of other French experimenters, between 6 and 7 pounds. These figures have not been improved upon to any great extent, except in isolated cases, up to the present day, so that it will be apparent that the aerial propeller is lamentably inefficient, and that most of the recent successes have obtained in spite of its shortcomings, rather than otherwise. The cost of this is redundant power and weight, since the propellers waste a very substantial fraction of the energy supplied by the motor. This extravagant provision of excess power that is necessary likewise involves a larger, stronger, and heavier machine as a whole, for a given passenger-carrying capacity.

Propeller Construction. *Material.* In actual propeller construction various expedients have been tried by the French and while some of these propellers have been ingenious, the example thus set has not been generally followed. The Antoinette is one of the very few machines, if not the only one, that employs a metal propeller. Bleriot experimented with metal propellers in the early days but shortly abandoned them for wood, which he has since adhered to. The Antoinette propeller has a diameter of 7 feet 2 inches and a pitch of 4 feet 3 inches. It is composed of a stiff steel tube to which are attached two blades of sheet aluminum riveted to it. The blades themselves, however, are adjustable, thus permitting of varying the pitch. It is designed to run at 1,100 r. p. m. The Vendome is a hollow two-bladed propeller, 8 feet in diameter, which is built of hickory veneer, mounted on canvas, so that despite its size, it weighs only 4.4 pounds. While this represents exquisite workmanship and a beautiful finish, an extremely light weight is no advantage, particularly where the propeller is relied upon to act as a substitute for the flywheel of the motor, as is generally the case. The Tatin, another French example, is a two-bladed propeller built up of laminated wood, and represents one of the rare instances in which the design calls for a pitch exceeding the diameter. The latter is 7 feet 8 inches, while the pitch is 8 feet 2 inches, the propeller being designed to run at 700 r. p. m., being driven through a reducing gear. Its construction is peculiar in that instead of being built up by simply gluing one board over another, a number of thin superimposed sheets or laminations of wood are let into framing, the whole being covered tightly with Japanese silk and then varnished.

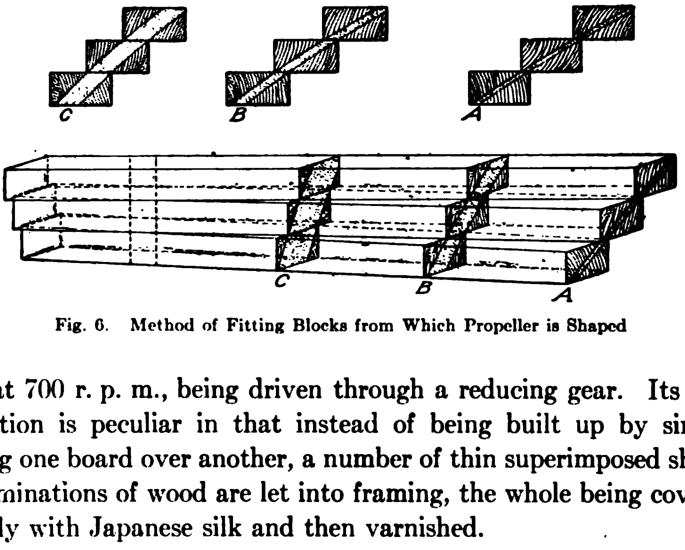


Fig. 6. Method of Fitting Blocks from Which Propeller is Shaped

Standard Construction. The standard method of propeller construction, in that it is now most generally followed, is that of gluing a number of boards together under heavy pressure and then practically whittling the propeller out of the block thus formed, Fig. 6. Wood is preferred to steel for a number of reasons, chief among which is the liability of a steel blade to snap suddenly and without warning under the influence of temperature changes or violent shocks. If sufficiently strong, a wood blade is less liable to snap, and gives warning of impending fracture by bending and splitting. Wood propellers are also much lighter than those of steel. The blade of an aerial propeller has sharp edges, particularly on what is termed the "attacking edge," but it is quite thick along its median line. It is made thick, not merely to strengthen it, but because thickness offers the same aerodynamic advantage in the propeller that it presents in the sustaining surfaces of the aeroplane. This thickness gives ample strength when the material is wood, while it would make a steel propeller unnecessarily strong and excessively heavy, though, for that matter, it would be possible to employ sheet-steel stampings or pressed steel, autogenously welded together. In this case, the expense for dies would be prohibitive unless propeller designs were standardized, so that wood has the advantage of being much easier to work than steel.

Chauviere Method. The Chauviere propellers, used on most French machines, are built up of several planks of well seasoned ash or walnut. These planks are cut to the shape of a number of sections transverse to the axis of a propeller designed in accordance with the special conditions proposed, such as the r. p. m. rate at which it is to turn, torque, tractive effect, and the speed for which the aeroplane itself is designed. Each plank forms part of both blades of the 2-bladed propeller and therefore a hole is cut into the center to receive the hub. The planks are then glued together on their faces, after having been accurately centered and orientated, so that they represent the form of the finished propeller approximately and show some of its lines accurately. The next operation consists of removing the superfluous wood between these lines and working the entire surface to the required form. This is a delicate task requiring great skill and care, for the removal of too much material at any point would ruin the work. The surface is finished by polishing.

A still more delicate operation is necessary to balance the blades, as even a slight difference in length, weight, or shape might set up dangerous vibrations in a rapidly revolving propeller. The propeller is mounted on a mandrel, which is poised on very sensitive friction wheels in a specially-devised machine, and the blades are carefully retouched until the propeller remains in equilibrium in every position. It is then coated with special varnish to give it a smooth surface and to protect it from the weather. The finished propeller is firmly attached to the shaft by clamping its central portion between two steel disks, connected by bolts passing through the wood of the hub.

American Methods. Two methods are in vogue in this country at present. In one, the planks forming the propeller are offset upon one another in such a manner that when the superfluous wood represented by their protruding edges is removed, the surface thus obtained is the curvature desired in the finished propeller. The planks must, accordingly, be finished very accurately before gluing and must be put together very accurately to insure this result. The other method, which is that mentioned in the article on "Building a Curtiss biplane," and illustrated therein, Fig. 21, is merely to glue the planks together in such a manner that sufficient excess material is allowed, back and front, to whittle the resulting block down to the required dimensions and shape. Templates, representing the curvature of the back and front at sections 3 inches apart from the hub right out to the tip, are employed to note the accuracy of the work as it proceeds. The greatest care must naturally be employed not to cut too deep at any point. In either case, the finish is the same—rubbing smooth, polishing, and varnishing. Ever since the accident to the propeller of the Wright machine in which Lieutenant Selfridge was killed at the United States Army acceptance tests in 1908, it has become customary to protect the tips of wood propellers by covering them for a foot or more from their ends with cheese cloth, or other light fabric. This cloth is stretched on very tight, like a pocket covering the end of the tip, and is glued down and varnished, so that it practically becomes a part of the wood and there is no break in the surface. Some such protection is necessary to prevent splintering when accidentally striking objects, particularly when on the ground, as the propeller tips are very thin and correspondingly fragile.

The method of gluing the planks together in fan shape so that the points at which the planks overlap will practically mark the line of curvature of the finished blade, is that followed in the making of the Wright propellers. Contrary to the custom of employing ash, maple, walnut, and other hard woods, or alternate laminations of these with spruce, the Wright Brothers pin their faith to spruce alone, as is the case in the construction of the entire framing of their machine, with the exception of the bed for the motor. The Wright propeller is built up of three planks glued together as shown in Fig. 6, so that they overlap like the sticks of a fan to an extent which diminishes as the distance from the axis increases. The superfluous parts of the wood represented by the dark and triangular areas of the upper diagrams in the figure, are then cut away, the curvature being tested at every point with the aid of templates as the work proceeds. In contrast with this, Chauviere propellers are made from six or seven overlapping planks. The finished propeller contains only about 8½ per cent of the wood of the original planks. A study of the sections, *A*, *B*, and *C* in Fig. 6 will make clear both the progressive variation in slope and the curvature from the axis to the periphery, and the corresponding variation in the thickness of the blade. The general direction of these sections will be more or less inclined to the axis of the propeller according to their distance from it. In the making of metal propellers, the blades are usually riveted to the arms, composed of steel tubes brazed into the hub. The blades themselves are then given the proper curvature by hammering upon a form. Casting in the form desired and twisting into shape have both been tried, but without much success, very few metal propellers of any kind being in use today.

Hollands. A recent British patent on an all-steel propeller is of interest. It is known as the Hollands propeller and is formed of thin steel plates, brazed together at their edges. In cross section the blades are of shell-like form concave on the driving side and convex on the leading surface, the concavity being less than the convexity. The greatest depth of concavity equals one-eighteenth of the width of the blade, and is situated at one-third of the breadth from the leading edge throughout the length of the blade. The blades taper from root to tip and are set at a gradually decreasing pitch angle, being 15 degrees at the tip and 30 degrees midway the length of the blade. An efficiency of 85 per cent is claimed for it on the ground that it has a minimum radius of centers of pressure and mass, resulting in minimum torque in relation to thrust, or greatest thrust for a given turning moment, least centrifugal stress for a given angular velocity and diameter, and the least bending moment on the blades.

Propeller Design. *True-Screw Type.* There are two forms of propellers extant, the true-screw and the variable-pitch, the former being very largely in the majority, in fact, used almost altogether, although the variable-pitch type likewise has its advocates. The effect of revolving an aerial propeller, as already explained, is to create a column or shaft of air out of the body of air in which it is run, of a diameter nearly corresponding to the diameter of the propeller, the column being given, by the pitch and rotation of the blades, a backward motion proportionate to the power delivered to the propeller, the movement of the latter being similar to that of a nut when being moved along a bolt in the operation of loosening. The underlying principle of the screw thus being necessary, it is essential that the propeller, which is the column-forming instrument, should be true to work with the greatest efficiency; it should run through the column within the main body in the same way that a well-made nut worms its course along a well-made bolt. Each part of the bolt-engaging surface of the nut must engage with the surface of the "fluid-bolt" it creates, with equal pressure throughout the whole of its convolutions. Any distortion or lack of trueness in the thread of an ordinary nut will effectually spoil its bolt by stripping the thread to some degree, in other words, ruining its engaging surface while coincidently taking a uselessly large amount of power to force it along the bolt. The same principle applies in the case of the propeller, and if the blades are distorted, rough, or untrue, they will act in the same manner as the badly-made nut and waste a great deal of the power exerted in driving.

On the true-screw principle, the effect of the propeller in the air must start from the point where the blade springs from the hub and continue right through its entire length and surface. Each blade must accurately match its counterpart and be fixed in relation to it so that at no point will one part of the propeller try to climb through more air, or worm through any more or less of its true course, than it should. If not properly and accurately made, instead of thrusting backward a clean-cut column of air, it will simply churn and worry it with a great loss of power. But a propeller which is true screw in shape, may be very untrue in its action on the air. To be efficient, it must act as a whole upon the air, as a true screw nut does upon its bolt. In other words, the best propeller for any particular case may have greater or less angularity of its blade at various places, than would be called for if the propeller were designed to be a true-screw shape for the particular pitch speed required. In any case, it must be a true screw in its operation. As mentioned in connection with the details of building a Curtiss biplane, the number of aeroplane designers competent to build a properly-made variable-pitch propeller is very small indeed, which probably accounts for the small number in use. Moreover, the advantages claimed for it appear to be so largely based upon theory as to provide small incentive for its adoption.

Some idea of the dynamics of the action of the aerial propeller may be gained by citing a very simple illustration. Take the case of a smoker "blowing rings." It will be noted that a cylinder of air is propelled from the mouth into the still air of the room. At the edge of this cylinder of air is the smoke ring, and it will be evident that it revolves within itself, the inside traveling forward and the outside of the ring to the rear. This is obviously due to the friction between the moving cylinder of air and the still air through which it travels. This action is more markedly apparent in the smoke rings that issue from saluting guns and from locomotive stacks under favorable atmospheric conditions, but equally effective results may be obtained with a "smoke ring box," made from an ordinary stationery box with a circular hole cut out of the center of the cover. Fill this with smoke and tap lightly, to compress the air within, and a ring will be emitted. A hard tap will cause a clear, sharp ring to shoot rapidly upward, but by raising the box cover slightly and gently lowering it, a series of rings will emerge and float slowly up, affording sufficient opportunity to study their evolutions closely. In any case, when a smoke ring is produced, its center is very small and grows larger as the ring expands. It is with the first stage of the ring that we will deal.

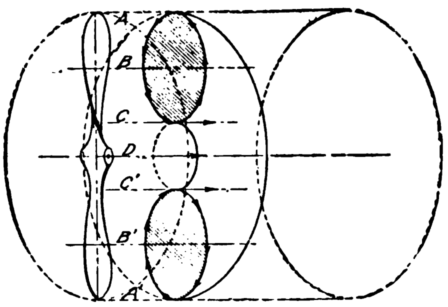


Fig. 7. Diagram Showing Action of Propeller Blades

Assume the two cross-hatched ellipses of Fig. 7 to show the section of a smoke ring, cut through its center. The ring, acted upon by a force in the direction of *D*. revolves within itself as shown by the arrows. Friction with the outside air mass causes this rotation and reduces the velocity of the extreme edge of the ring to zero, as shown at *A* and *A'*. This ring then apparently rolls inside a tube of air, and as its maximum velocity is at *C* and *C'*, the points *B* and *B'* must attain a velocity equal to one-half that at *C* and *C'*. The portion between *C* and *C'* forms the shank and hub in most propellers and does not assist materially in propulsion, if at all. The above may be taken as the relative velocities of various portions of the disk of the air column sheared loose by the slip of a screw-pitch propeller while traveling through the air at its normal speed.

Variable-Pitch Type. Taking a screw-pitch propeller, blade incidence angles (blade angles not corrected for slip) are found at the different radii corresponding to Fig. 7, to be as follows: At *C* and *C'*, 14 degrees; at *B* and *B'*, 7 degrees; and at *A* and *A'*, 3½ degrees. Now the velocity at *C* and *C'* is twice as great as at *B* and *B'*. In order, therefore, to raise the velocity at *B* and *B'* to that at *C* and *C'*, we must increase the blade angle of the propeller as much again, or from 7 to 14 degrees. The velocity at *A* and *A'* being practically zero, it will be necessary to increase the blade angle considerably at this radius. Doubling the blade angle at *B* and *B'* has doubled the velocity at this point; hence, increasing the blade angle at *A* and *A'* (3½ degrees) to the former angle of *B* and *B'* (7 degrees), should give this radius the former *B* and *B'* velocity, or one-half that of *C* and *C'*. By doubling this angle, *i. e.*, increasing it to 14 degrees, we again reach the velocity of *C* and *C'*.

These angles may then be assumed to give a *slip column* of air of uniform velocity, and as such a column of air is what the propeller pushes against, the *slip column* would give a more efficient background for *propeller purchase*, so to speak, than the *varied velocity column* delivered by the screw-pitch propeller. This constitutes an argument for the uniform pitch propeller, it being noticeable that the products of increasing and doubling the various angles result in each case in the same angle, namely, 14 degrees. Correcting this angle throughout its length in order that the theoretical and practical foot pitch may agree, add, say, 2½ degrees, and the result will be a uniform or straight-pitch propeller, with a blade angle of 16½ degrees.

From what has been said thus far, it will be apparent that there is considerable diversity of opinion regarding the design of the propeller, and likewise a lamentable lack of definite knowledge regarding propeller efficiencies. Since errors in the design may necessitate a motor of 30 to 100 per cent more power to attain the desired result, the importance of working along well-settled lines will be manifest.

Problems in Design. The salient points of design already dwelt upon, putting them in the form of questions which must be answered by the designer when planning his propeller, are as follows:

1. At what speed should the propeller be revolved to give a certain thrust?
2. What combination of pitch and number of turns per minute would produce the maximum thrust with the minimum power?
3. Is it better to use a fine pitch and revolve the screw fast?
4. Or is it better to use a coarse pitch and turn the screw slowly?
5. Are wide or narrow blades preferable?
6. Should the blades have a uniform or an increasing (variable) pitch?
7. Which is preferable to use, two, three, four, or more blades?
8. Given two screws exactly alike, but one with two or three times the diameter of the other, how much more thrust should the larger one give than the smaller when revolved at the same speed?
9. How much more power is required to obtain a given number of pounds thrust while traveling at 20, 30, or 40 miles an hour, than to give the same thrust when standing still?
10. What percentage of the power used is due to skin friction?

Propeller Tests. *Herring.* To obtain propeller data, Herring, long associated with Curtiss, devised the apparatus shown in Fig. 8. On this a great many propellers have been tested, both in still air and in a powerful blast of definitely known velocity, to simulate the condition of traveling through the air. M represents a variable-speed electric motor of 5 horse-power. This is rigidly mounted on a table, and by means of resistances and a controller, may be kept running steadily at any speed desired between 700 and 1,500 r. p. m. The propeller to be tested, V is mounted on a shaft T on which is mounted a pulley P. This shaft runs in ball bearings W and U, and is held in place in the room by six wires H', H'', etc. These suspended wires have turnbuckles inserted in them for the purpose of adjustment, and very stiff springs for taking up the vibration at high speeds. An endless belt connects the motor pulley

R with the pulley *P* on the propeller shaft. This belt passes under the ball-bearing, mounted pulleys *N* and *O*, which have suspended from them the equal weights *C* and *D*, for the purpose of keeping the belt taut. In testing, the speed at which the propeller is turning is measured at *W* where the shaft projects through the bearing.

The amount of power in foot pounds per minute used in driving the screw, is the pull on the belt multiplied by its speed. Or, to be more exact, it is the pull on the belt multiplied by the number of turns of the pulley *P* per minute, multiplied by the circumference of this pulley in feet. The circumference of *P* can be directly measured, while the pull on the belt is always exactly half the reading of the scale *B*. The thrust of the screw is measured direct by means of the scale *A*, which is connected by a wire with the bearing *U*. A stop *S* prevents the shaft *T* from moving back beyond a certain point. An electric contact *E* and the lamp *L* show when the propeller pulls enough to move the bearing away from *S*.

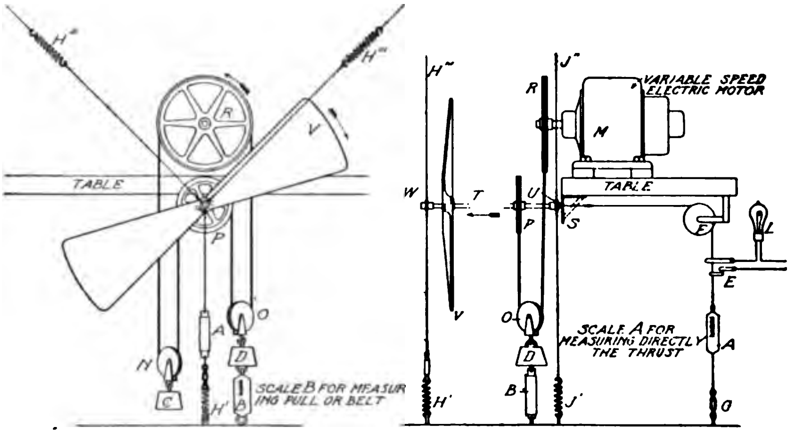


Fig. 8. Herring's Apparatus for Testing Propeller Thrusts and Amount of Power Developed

The turnbuckle *G* is used for adjusting the force with which the propeller axle is held against the stop *S*, which force must be overcome before the lamp *L* glows. This force—the actual thrust of the screw—is measured direct on the scale *A*.

Screws ranging from 7 inches to 4 feet in diameter were tested at some 15 to 20 ranges of speed each, and screws with wide and also narrow blades, but of the same diameter and pitch, were tried. Also screws of the same number and width of blades, differing only in pitch, were tried. A screw of 40-inches diameter and having no pitch was also tested at many speeds to determine the power absorbed in skin friction. As the apparatus was built with extreme care and fine ball bearings were used throughout, its friction was found to be surprisingly small—so small in fact, that even in the experiment on skin friction, the forces could be measured with accuracy. Incidentally, the reduction of the thrusts of the various screws caused by wind pressure against the pulley *P* was arrived at with considerable accuracy by substituting pulleys of different diameters, and noting the change in the thrust of the screws when running at the same speed.

To obtain an idea of the relative values of different designs of screws under conditions of actual practice, a second motor which does not appear in the drawing, was mounted in front of *W*. A propeller was mounted direct on the shaft of this second motor, and made to furnish a blast in which the screw being tested worked. As the second motor also could be driven at any desired speed, and the blast from it accurately measured, the screws were tested under conditions which closely approached those to be expected in practice, when the aeroplane is moving through the air in flight.

The results embraced some 900 or more readings and showed in a striking manner that comparatively slight differences in design may easily mean great saving or waste of power. By placing an obstruction in front of the propeller when it was revolving in still air, more thrust was obtained than was theoretically possible. Blocking the flow of air at the side of the propeller had a tendency to diminish the thrust.

While this testing apparatus more or less approximates conditions of practice, it is evident that a uniform blast of wind is far from representing the actual condition under which a propeller has to work, so it would seem that the only conclusive test of a propeller is to try out the screw itself under practical flight conditions. But this may be a risky undertaking, either in a dirigible or an aeroplane, and more particularly the latter, as through some error in design, it may fall so far short of calculations as to be a menace to the safety of the aviator.

British Tests. The English firm, Vickers Sons & Maxim, who were responsible for the construction of the huge British naval dirigible, have gone to great expense to build a testing apparatus for this purpose. It consists of a great whirling table. From a high tower of steel erected on a hill at an open place, is hung a big cantilever. The arm on which the propeller is mounted is 110 feet long, and is balanced by an arm 56 feet long and carrying a water-ballast tank at its outer end. Both arms are built up of steel angles and are tied by steel rods to a bracket at the top of the tubular tower. At the head is a large ball bearing which supports the entire weight of the moving part of the structure, while a guide for the bottom end is supplied with four horizontal rollers carried on cast-iron brackets bolted to the lower end of the steel tube and rolling on a turned track on the collar.

For the motive power, there is a 100-horse-power engine situated in a cabin built round the tower on the revolving arms. A line of shafting carries the power to the extremity of the propeller testing arm and drives the propeller through bevel gearing. The propeller is mounted on a sliding shaft which works against a spring thrust abutment. To reproduce actual working conditions more thoroughly, a car is rigged up, and resistance can be put upon the arm to vary the speed at which it rotates. This motion of the arm is due entirely to the propeller thrust, and this thrust can be measured accurately to within 1 per cent, a special device being introduced to compensate for the circular flight path. Although one of the reasons for the erection of this monster propeller testing plant has been to promote the trials of the new screws for the naval dirigible, it is also employed for other tests and is open to British military and various experimenters.

Number of Propellers. The number of propellers and their location on the aeroplane are also considerations of importance which form part of the problem of propulsion. The chief reason for urging the use of plural propellers is to overcome the unbalancing brought about by the gyroscopic effects and those of reaction, it being evident that they can be readily neutralized by the use of two or more propellers of the same size, symmetrically placed and revolving in opposite directions. That such effects exist can not be denied, but the prevailing opinion is that their magnitude with propellers ranging from 5 to 10 feet in diameter and weighing from 3 to 20 pounds, with a large proportion of this weight in the hub, is too trifling to be seriously regarded—a view that is apparently upheld by the fact that the Wright and Cody biplanes are the only successful twin-screw machines of large size, *i.e.*, not flying models. This system was first seriously applied by Maxim to his huge multiple-plane machine and was subsequently employed by Langley on his flying models. It certainly appears logical that a narrow propeller blade from 2 to 5 feet long, moving at high speed on one side of an aeroplane, can not produce any considerable reaction per unit of area against a broad wing surface on the opposite side, from 10 to 25 feet long.

For instance, take Bleriot's cross-channel machine. In this the propeller blades are $3\frac{3}{8}$ feet long and the wing span 25 feet. The most effective speed of this propeller is about 1,200 r. p. m. at which about 25 horse-power is required. This amount of power is equivalent to 825,000 foot pounds a minute, or 688 foot pounds a propeller revolution, meaning that the two propeller blades encounter a maximum possible resistance to their rotation of 688 divided by 21, the approximate surface in square feet of the propeller circle or disk. This gives an approximate resistance of 33 pounds, figured at the propeller tips, which, extended to the wing tips, is the equivalent of a trifle over 8 pounds load on the one wing end, raising the weight supported per square foot of area an average of one and two-thirds ounces higher on one wing than on the other. Assuming a normal load of 75 ounces to the square foot, which is very close to the actual, the addition of this amount unbalances the machine to the extent that the weight is only 2 per cent more on one side than on the other.

Wilbur Wright asserts that the Wright machine can be flown with 50 pounds of unbalanced weight, and Santos-Dumont has flown with 40 pounds on one side of the body of his monoplane, nothing more than a slightly increased warping of the wings on one side being necessary to correct the balance, from which it will be apparent that the unbalanced reaction from a single propeller is not as serious in practice as it is in theory.

The gyroscopic action of the single propeller is more dependent upon the factors of mass and speed. With heavy propellers, it might undoubtedly become serious, but with the light wood propellers so generally employed, it is quite as negligible a quantity as the reaction effect.

Location of Propellers. The most important single question of design still unsettled is the position of the propeller. There is a distinct advantage in placing the propeller at the rear in marine practice, utilizing a pushing or propulsive action, on account of the frictional wake created behind the ship, and which causes the water to flow after the vessel, but at a lesser velocity. In placing the propeller behind, it is put in such a position as to act upon and take advantage of this phenomenon, the effect of the propeller being to bring this wake to rest.

Theoretically, a boat can be propelled with less power than is necessary to tow it, but with respect to aeroplanes, apart altogether from the difference of mediums, there is at present a very considerable difference of form, an aeroplane bearing but little resemblance to the hull of a boat. Undoubtedly there is a frictional wake in the case of the aeroplane, perhaps quite as much as in the case of a boat, allowing for the difference in medium. Admitting then that this wake does exist, it follows that a propulsive screw is better than a tractor. In a matter of this kind, constructional considerations, as well as ease of launching and ability to land without damage, must be given due weight. In the case of monoplanes, constructional details have had most to do with the use of the tractor or forward position of the screw, but monoplanes are now being built with propulsive screws. Good results have been obtained in a small flying model equipped with two screws, placed fore and aft in line with one another, the forward screw being a tractor and the latter a propulsive screw, but so far as the writer is aware this arrangement has never been tried in actual practice.

Experience has shown that no improvement whatever is obtained where efficiency is concerned, either by the use of a ring connecting the propeller blade tips, or by the employment of any form of shrouding. It has frequently been considered that locating the propeller in a cylindrical or conical chamber, or employing some form of guide through which the air is led to the propeller is necessary, and quite a number of machines—few of which have ever flown, by the way—have incorporated this feature. That nothing of this kind is an improvement, either when placed before or behind the propeller, is now self-evident. The air does not fly off from the tips of the blades under the influence of centrifugal force, as has been commonly supposed, but is powerfully drawn inward in a well-designed propeller, so that the maximum efficiency is obtained by allowing it to revolve in a free air space.

Propeller Efficiency. The efficiency of a propeller depends upon two fundamental laws—the law of kinetic energy and the law of momentum. A propeller rotating upon a standing machine discharges a certain number of pounds of air backward every second. The law of kinetic energy is expressed by the equation

$$W=\frac{64\ K}{V^2}$$

where K is the number of foot pounds of energy which, when applied to a body, or volume of air, of W pounds weight, will give it a velocity of V feet per second.

The law of momentum is expressed by the equation

$$F=\frac{W\ V}{32\ T}$$

where F is the force in pounds, which, applied to a body, or volume of air, of W pounds weight for a time T seconds, gives it a velocity of V feet per second.

But there are two meanings of the term "propeller efficiency." One, the *true efficiency*, is the useful work of the propeller, divided by the power absorbed by it. The useful work is the speed of the aeroplane, multiplied by the thrust of the propeller while driving the machine at that speed, and, of course, the power absorbed is the brake horse-power (in foot pounds) of the engine at the number of revolutions made under those conditions, less the power lost in transmission.

The other meaning of propeller efficiency is simply the *thrust exerted by the propeller* when revolving at a fixed point, multiplied by the pitch velocity, and divided by the foot pounds delivered to it by the engine.

The pitch velocity is the pitch times the number of revolutions per minute.

It is efficiency in the latter sense that is considered here, and a comparison of two propellers of different diameters will show, in a striking manner, the increase in efficiency with increase in diameter. Take, for example, two propellers rotating on standing machines using the same horse-power, but of different diameters. The given horse-power acting on the smaller amount of air in the smaller propeller gives the discharged air a higher velocity than with the larger propeller. This velocity corresponds somewhat to the slip in a propeller on a moving machine and should not be mistaken for the velocity of the machine.

Let the two propellers be of such sizes that, for one horse-power applied to each, the velocity given to the discharged air by the small one would be 40 feet per second, and by the larger one 20 feet per second. One horse-power is equivalent to 550 foot pounds of energy expended per second. Consider the law of kinetic energy as applied to the volume of air discharged in one second by the two different propellers. We have for each propeller, $K=550$ foot pounds; $V=40$ and 20 feet per second, respectively. Then the weight W of air discharged by the small propeller in one second is

$$W=\frac{64\ K}{V^2}=\frac{64\times 550}{40^2}=22 \text{ pounds of air}$$

Again, for the larger propeller

$$W=\frac{64\times 550}{20^2}=88 \text{ pounds of air}$$

Now that we have the values of W, or the weights of the air discharged in each case, we can apply them in the equation of momentum and ascertain the force applied to the air, or the thrust of the propellers.

For the smaller propeller we have

$$F=\frac{W\,V}{32\ T}=\frac{22\times 40}{32\times 1}=27.5 \text{ pounds thrust}$$

Again, for the larger propeller

$$F=\frac{88\times 20}{32\times 1}=55 \text{ pounds thrust}$$

Of course, in these calculations, the losses due to skin friction and to the churning of the air, are neglected, but the figures show a striking comparison in favor of the larger propeller, both in having smaller slip and in giving a higher thrust than the smaller one for the same amount of energy in each case expended in producing slip.

SCENE AT AN AVIATION MEET AT ROUEN, FRANCE, SHOWING AN ANTOINETTE MONOPLANE MAKING A TURN

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AERONAUTICAL PRACTICE

PART I

STABILITY OF THE AEROPLANE

Variations of Center of Pressure. When an aeroplane of any shape is placed at various angles in a current of air, it is found that the point at which thepressure acts, *i.e.*, the center of pressure, varies with every inclination. This variation or travel of the point of application of the center of pressure differs with every section and plan shape of aerocurve or aeroplane. With certain aerocurves and with all aeroplanes the center of pressure appears to travel continuously toward the front edge as the inclination is continuously decreased. In Fig. 1 is shown the locus of the center of pressure for rectangles having an aspect ratio of three to one in length and width aspects. In both cases the center of pressure continuously advances with decrease of inclination.

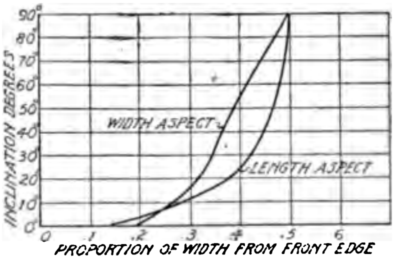

Fig. 1. Center of Pressure Curves for Rectangular Planes. Aspect Ratio 3 to 1

Fig. 2 shows a similar locus for an aerocurve having a camber of $\frac{1}{12}$ span, and an aspect ratio of 3 to 2, curve 2 representing the hollow upward and curve 1 the hollow downward. The curve 2 indicates strong stability, and the curve 1, an absence of stability. These and the following curves of the center of pressure were taken $\frac{3}{60}$ inch above the highest point in the plane, the greatest dimension of the plane being 9 inches. A. P. Thurston, who made the series of experiments here recorded, found it preferable to obtain corresponding curves in

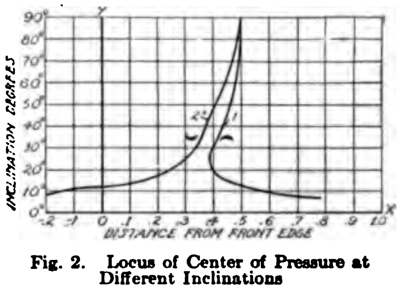

Fig. 2. Locus of Center of Pressure at Different Inclinations

addition below the planes, since the resultant pressure becomes more inclined to the normal as the inclination of the plane is decreased. Then, by the combination of the two curves so obtained, it is possible to find the travel of the center of pressure for any other parallel line. The stability of a flying machine depends upon the continuous travel of the center of pressure toward the front edge with decrease of inclination.

Conditions for Stability. The center of gravity and the center of pressure coincide under normal conditions when a flying machine is running at the natural angle and speed, but when the angle is too small, the center of pressure approaches the front edge and forms, with the weight, a couple tending to restore the machine to its natural inclination. Conversely, if the inclination be too great, the center of pressure travels behind the center of gravity and forms a couple tending to decrease inclination. It follows, as the first necessary condition for maximum stability, that the travel of the center of pressure to either side of the center of gravity should be a maximum for a minimum alteration in the angle of inclination.

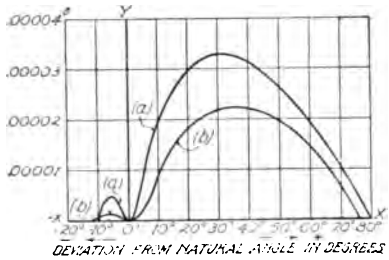

Fig. 3. Stability Curves for Rectangular Planes

As the second condition, it follows that the moment of inertia of the machine about a lateral axis through the center of gravity should be a minimum, since the inertia of the machine resists the action of the restoring couples. The restoring couple at any point is the product of the lift by its distance from the vertical through the center of gravity. Since the lift is a function in the equation of stability, it follows, as the third condition for maximum stability, that the decrease of lift with decrease of inclination should be a minimum. In the ideal condition, the lift should increase as the inclination is decreased from the natural angle. This is, of course, impossible in practice. If, when a machine has received a small displacement from the natural angle, a perpendicular through the center of lift is drawn to cut the line which passes through the center of gravity and which is perpendicular when the machine is at the natural inclination, a point is obtained the position of which affects the stability of the machine. This point, which, to coin an expression, might be called the "phugoid center" corresponds to the metacenter of vessels, and its height above the center of gravity gives a measure of the longitudinal stability of a flying machine.

In Figs. 3 and 4 are shown the stability curves of rectangular planes having aspect ratios of 3 to 1 in length and width aspects, respectively. Models were made and the centers of gravity carefully adjusted until the best flights were obtained. Good flights were obtained with center of gravity located 0.28 of the width from the front edge. The models were then pivoted about these points, and the vertical torque resisting a displacement from the natural inclination was measured; this is plotted in Figs. 3 and 4. Fig. 4 is an enlargement of a portion of Fig. 3. Curve *a* shows the plane in the length aspect, and curve *b* in width aspect. The rectangle in length aspect clearly has a much greater stability than the same rectangle in width aspect. The restoring torque is $\phi W A V^2$ pound feet, ϕ being the stability coefficient for any deviation from the natural flying angle and read from the diagrams, Figs. 3 and 4; W the width of plane in feet, back to front, taken in the direction of motion; A the area in square feet, and V the velocity in miles per hour.

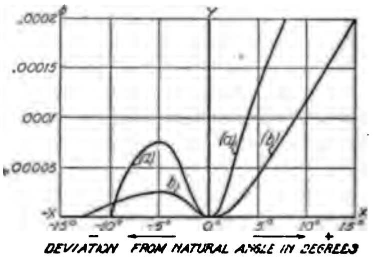

Fig. 4. Stability Curves. Enlarged Detail of Fig. 3

Methods of Increasing Stability. The stability of a machine may be increased by placing a second or rider plane in front of or behind the main plane. For maximum efficiency in flight, the main plane should have the shape and area giving the maximum lift efficiency, *i.e.*, it should be approximately a rectangle in length aspect. The shape of the main plane being thus fixed, it is possible to vary the shape and disposition of the rider plane only for the purpose of increasing the stability. Now the travel of the center of pressure might be increased if it were possible to cause the pressure on a front rider plane to decrease at a less rate than the pressure on the main plane, and, conversely, with a tail rider plane, to decrease at a greater rate than that on the main plane. This result may be obtained by each or all of the following means:

Placing a front rider plane at a positive angle with the main plane, i.e., at a greater angle to the air than the main plane, and a rear rider at a negative angle, i.e., at a less angle.

By utilizing the wake of the front plane to affect the back plane.

By the use of certain shapes and aspects of planes for the front and rear riders, respectively.

Front and Rear Rider Plane. If the front rider is at a positive angle, then, as the inclination decreases, it is obvious that the pressure on the main plane will decrease at a greater rate than that on the rider, since the rider will still be lifting when an angle is reached at which the main plane ceases to lift. Conversely, if the rider is set at a negative angle, then, as the inclination of the machine decreases the front plane will reach an angle at which it ceases to lift, and upon a still further decrease in inclination the air will act upon the top of it and introduce a depressing force. This force will oppose the couple introduced by the travel of the center of pressure. Thus it follows that the front rider should be set at a positive angle with the main plane. From a similar reasoning it follows that a tail rider should be set at a negative angle with the main plane. It will be evident that the original arrangement of the Wright machine with the front rider at a negative angle tended to decrease the natural stability of the biplane, and this was probably one of the causes that led to its abandonment.

"Wake Effects." Too little attention appears to have been paid to the utilization of the wake effects for increasing the stability. The air which is engaged by an aeroplane is deflected downward. This downward deflection is not confined to the air in the immediate run of the aeroplane, but extends to a considerable distance above and below the plane, particularly above. The field of an aeroplane is therefore greater than its run.

A series of original stream-like photographs taken with the aid of smoke in a current of air having a speed of 1,800 feet per minute demonstrated this very clearly. The stream of air flowed out of a small nozzle so that it could be positively directed at any point desired, the surfaces experimented with being models of the single and double surface elevating planes such as are employed on the majority of standard type monoplanes and biplanes. With the monoplane elevator set at a sharp positive angle and the current directed horizontally, the air considerably above the plane was noticeably influenced, while when directed straight at the edge of the plane the air divided in front of it, closely hugging the under side and forming a "surface of discontinuity" on the back. Directing it at the center of the plane, the angle of incidence being the same in every case, clearly showed the compression under the plane as well as the upward spring of the current at the rear to counteract the suction above; and directing the stream below the plane showed the gentle downward deflection imposed on the air below the rear edge of the plane, indicating that the air entirely below the plane is affected quite as much as that above it. From these experiments it will be apparent that the air at the rear of an aeroplane is in a considerable state of agitation which varies from point to point. Now the lifting effect of this air in the wake is not so good as that of undisturbed air; moreover, since this air has on the average a downward deflection, an effect is obtained on the rear plane similar to that obtained by placing it at a negative angle with the front plane. Thus the stability may be increased by placing the rear plane in the wake of the first plane; but there is an additional effect to be obtained by utilizing the wake.

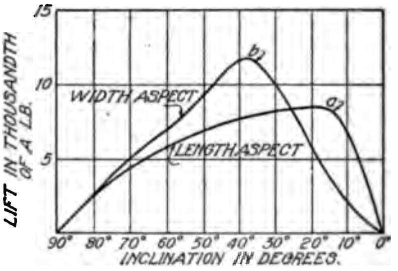

Fig. 5. Lift on Planes at Various Inclinations. Planes 3 × 1 Inches, Velocity of Air 21 Feet per Second

The purpose is to arrange it so that the lift on the rear plane shall decrease at a greater rate than that on the front plane. Since the lifting effect of the wake is not so good as that of undisturbed air, it follows that this object may be attained by arranging the rear plane to enter the wake when the inclination is decreased, and to come out of it into the free air when the inclination is increased. The best place for mounting the rear plane to obtain the maximum effect by this means can be determined only by experiment and by drawing the stability curves, as in Figs. 3 and 4, and the curves for the travel of the center of pressure, as in Figs. 1 and 2.

Rider Planes of Certain Shapes and Aspects. The third method of increasing the stability is by the use of rider planes having certain shapes and aspects; for instance, these shapes may take a square, rectangular, circular, semicircular, triangular, or other plan form. Of these a rectangle in length aspect and having the greatest aspect ratio has a greater lift per unit of area at small angles than any other shape. In Fig. 5, which is derived from Dr. Stanton's experiments on a plane having an aspect ratio of 3 to 1, the lift on the plane in length aspect at angles between zero and 20 degrees (see curve *a*) is much greater than that on the plane in width aspect (curve *b*). Moreover, for angles above 20 degrees the pressure decreases proportionately (curve *a*) at a less rate than in the case of the same rectangle in width aspect (curve *b*). Therefore, a rectangle in length aspect, and having a large aspect ratio, is the best shape for a front rider. The shape of planes having the greatest proportional decrease with inclination appears to be either a triangle with its apex to the wind, or a rectangle in width aspect. The superiority of the triangle in this respect has not been fully demonstrated by experiment, but it has proven unusually successful in some of the French monoplanes such as the Antoinette. It is clear that there is a greater proportional decrease with inclination for planes having a smaller width aspect. Therefore, it follows that the tail planes should have a smaller aspect ratio than the front planes.

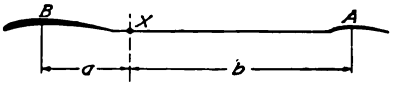

Fig. 6. Main and Tail Planes

The center of area of a triangle with its apex to the wind would be farther from the center of gravity of the machine than the center of area of a rectangle of equal area in width aspect. A greater restoring torque would, therefore, be obtained. Moreover, for equal areas of tail plane, a triangular tail would have double the span of a rectangular plane, and, therefore, take approximately double the advantage of the wake effect. It would thus appear from these considerations that a tail rider plane should preferably be triangular, with the apex toward the wind. Conditions represented by curves *b* and *c* (see Fig. 11) appear to require aspect ratios of opposite values; thus it follows that the relation of the dimensions should be fixed by experiment.

Methods of Producing Effective Damping Couple. The problem of stability is not completely solved by the provision of a suitable restoring couple. It is necessary to provide, in addition, an efficient damping couple to damp out any oscillation which may be set up. This damping couple is provided by the resistance offered to the planes as they oscillate in the air above the center of gravity of the machine. If, in Fig. 6, A equals area of the tail plane, B equals the area of the main plane and X is the center of gravity of the system, then $A \times b$ equals $B \times a$. Therefore, since the areas of both planes A and B are constant, the distances a and b must also be constant. For a given angular velocity of oscillation about the center of gravity X, the velocity v of the plane A is proportional to the distance b; and furthermore the resistance offered by the air to a plane is proportional to the square of the velocity. Therefore, the damping couple introduced by the rider plane A equals resistance $\times b$, *i. e.*, $v^2 \times A \times b$. But it has already been sated that v is proportional to b and, therefore, the damping couple is proportional to Ab^3 or to $Ab(b^2)$; *i.e.*, the damping couple provided by rider planes having equal control torque increases as the square of the distance from the center of gravity. The distance between the planes should, therefore, be as large as is practicable, which doubtless accounts for this characteristic of the most successful French monoplanes, such as the Bleriot, in which the fuselage or tail is extremely long. Also it follows that a triangular tail gives a more powerful damping action than a rectangular width aspect tail. From the previous reasoning it would appear that for maximum longitudinal stability,

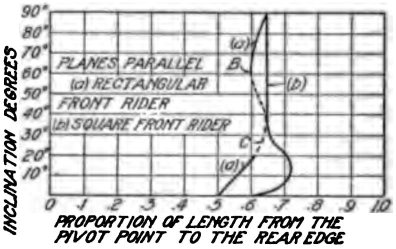

Fig. 7. Center of Pressure Curves for Plan Shapes of Figs. 8 and 10

(1) With the rider plane in front, the rider should have a large aspect ratio in length aspect, and a long span approximating to that of the rear main plane.

(2) With the rider plane behind, the rider should have a smaller aspect ratio than the front main plane, and should preferably be triangular with the apex toward the wind and placed so as to take advantage of the wake effects.

(3) In both cases the rider plane should be set as far as possible (within limits) from the main plane, the planes should be set at a positive angle with each other, and the moment of inertia of the machine should be a minimum.

Study of "Center of Pressure" Curves. Center of pressure curves for flying machines of various plane shapes and dispositions are shown in Figs. 7, 8, 9, 10, and 11. In all these cases the main plane is rectangular, 9 by 2 inches, the aspect ratio is thus 4½ to 1. This rectangle is fixed to one end of a rib with its length at right angles. The rider planes are adapted to be pivoted at the other end of the rib 7 inches from the outside long edge of the main plane. The curve *a*, Fig. 7, is obtained with a front rider plane 9×½ inch in length aspect. Its aspect ratio is therefore 18 to 1. Curve *b* is a corresponding curve with a square front rider of equal area to the last. In both cases, the rider and main planes are parallel. The increased stability obtained by the rectangular rider is apparent. If allowance is made for the increased longitudinal length of the model with a square front rider, the superiority of the rectangular rider is still more marked. Curve *a* between the points *B* and *C* was found to be unstable, it being found impossible to obtain definite points of balance.

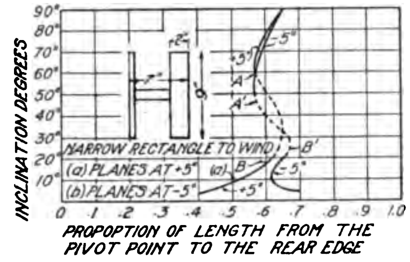

Fig. 8. Center of Pressure Curves for Plan Shape Inset

Fig. 8 shows curves *a* and *b* obtained with the first model, having the rectangular front rider at a positive and negative angle of 5 degrees, respectively. Curve *a* is obtained with the rider at plus 5 degrees with the main plane. This disposition gives a strong stability. In curve *b*, with the rider set at a negative angle with the main plane, there is a lack of stability, the center of pressure traveling toward the rear for all decreases of angle below 13 degrees. The curves were also found to be unstable between the points *A*, *B*, and *A'*, *B'*.

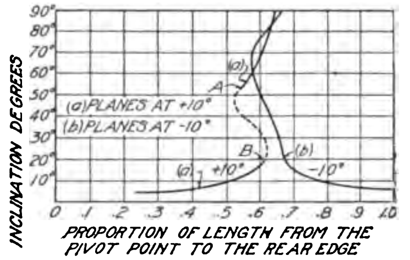

Fig. 9. Center of Pressure Curves for Plan Shape of Fig. 8

Curves *a* and *b*, Fig. 9, show the same model with the rectangular front rider at plus 10 degrees and minus 10 degrees, respectively.

Curve *a*, with the rider at plus 10 degrees, shows a stronger stability than the previous curve *a* of Fig. 8, and curve *b* shows a correspondingly greater lack of stability. Again it was found impossible to obtain definite reading between the points *A* and *B*, but no such difficulty was found with curve *b*.

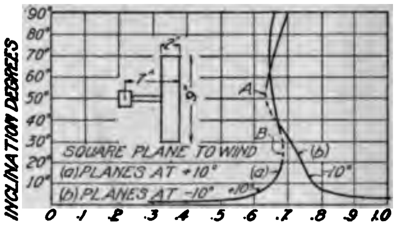

Fig. 10. Center of Pressure Curves for Plan Shape Inset

Fig. 10 shows curves corresponding to those in Fig. 9, but with a square front rider of equal area. The planes are set at plus 10 degrees and minus 10 degrees, respectively, in curves *a* and *b*. These curves are very similar in characteristic shape to those of Fig. 9, but in neither case is the stability or instability so strongly marked. The portions of the curves indicating the stability lie between 3 and 15 degrees. It is clear that the travel of the curves between these inclinations is smaller in Fig. 10 than in Fig. 9. Curve *a* is discontinuous between the points *A* and *B*.

Fig. 11 shows the center of pressure curve for a Bleriot disposition with a rectangular main plane and a triangular tail rider. The planes are in all cases at plus 10 degrees to each other. Curve *a* shows great stability. The center of pressure travels in front of the front edge of the main plane. The equilateral triangular plane is pivoted at its centroid and has an area equal to the square and rectangular riders previously used. It is mounted at the rear of the main plane with its apex to the wind. In curve *a* the triangular plane is mounted $\frac{3}{32}$ inch below the main plane and in curve *b* $\frac{3}{32}$ inch above. The difference in the curves *a* and *b* is therefore to be attributed solely to the wake effects. Curve *a* gives a superior stability to curve *b*. Curve *c* is obtained with the model used in curve *a* with the same angle, the current being reversed. Thus

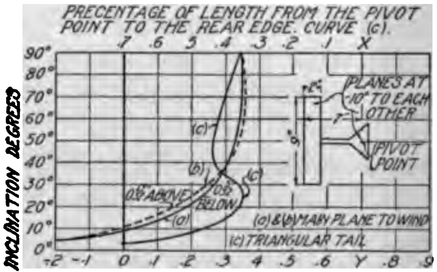

Fig. 11. Center of Pressure Curves for Bleriot Plan Shape Inset

the main plane becomes a rear plane, and the triangular tail a front elevator with its base to the wind. The line $X Y$ is the vertical base line for this curve, and corresponds with the back of the main plane. Curve c has been superposed on curves a and b to show the effect of plane shape and disposition on the travel of the center of pressure and the stability. These experiments were carried out in the aerodynamical laboratory of the University of London.

It will be apparent that the problem of stability resolves itself into keeping the center of pressure and the center of gravity in the same vertical line while sailing through the rolling masses of air that constitute every wind, the principle being exactly the same as in the dirigible although in the latter the putting it into practice is not attended by as many complications. The first investigators tried to do this in their gliding experiments by shifting their weight while gliding, but found it a difficult and, at times, an impossible task. For instance, Lilienthal, after making more than a thousand successful glides, was overturned and killed. The first successful departure from this crude method was that of the Wright Brothers who employed a horizontal rudder or rider some distance in front of the main plane, by which the machine could be prevented from overturning frontward or backward. This principle—that of operating stabilizing planes to overcome or to counteract every variation of the position of the center of pressure due to changes in the velocity and direction of the wind as originated by the Wrights—was what made flying possible, and it is now employed on every successful aeroplane. As demonstrated by the experiments just recorded, however, it was found that the front rider did not take advantage of the wake effects and was not as efficient a preserver of stability as the rudder in the rear; later Wright machines all were built in this manner, the only surfaces forward of the main planes being two small, fixed fins or keels to give greater inherent lateral stability. In all monoplanes, the stabilizing surfaces are at the rear and some distance behind the main plane, it being possible to reduce the area of these surfaces in proportion to the increased leverage afforded by their greater distance from the main plane.

With the elevators and stabilizing planes of moderate size and placed at moderate distances from the center of gravity, the balance of the aeroplane may be kept under control in the most irregular winds, provided these auxiliary surfaces are always set at the proper angle to give the desired restoring effect as determined by the rapidly shifting conditions. But when it is recalled that, at times, even the birds are upset by gusts of wind, and sometimes fall to the ground before they can recover their equilibrium, it is not surprising that occasions should be encountered in which the most experienced aviator is not quick enough to set the rudders to meet every gust. It is, therefore, essential that the aeroplane should be possessed of sufficient inherent stability to supplement the aviator's efforts in times of emergency, or that it be equipped with a controller which will automatically adjust the balancing surfaces independently of the aviator. The latter is a subject that is at present engrossing the attention of many of the foremost investigators in this field and it is treated of in detail under the head of Automatic Stability.

Longitudinal and Lateral Stability. The principle on which the inherent fore-and-aft, or longitudinal stability of an aeroplane depends is comparatively simple. The center of gravity of the machine is placed in front of the normal center of air pressure, and the forward planes are inclined at a greater positive angle to the line of flight than the following planes. If an aeroplane so adjusted be allowed to fall from a great height, since the center of gravity is forward of the normal center of pressure, the front will turn down and the machine will dive toward the ground. Then, when it has gained sufficient speed from gravity, since the forward rider has a greater angle of incidence than the main planes, the front receives a proportionately greater air pressure and the machine rights itself. This is strikingly illustrated by the foolhardy performance variously termed the "high dive" and the "dip of death," practiced by professional aviators at public meets, in which the machine is allowed to descend from a height of 1,500 to 2,000 feet at an angle of 45 to 60 degrees until it has attained a terrific speed, and then suddenly tilting the elevating planes when within a few hundred feet of the ground, thus bringing the machine up sharply on an even keel, and incidentally putting a frightful strain on every part of the aeroplane. As soon as the front of the aeroplane turns up again, its speed diminishes until the front again drops, and in this manner its flight through the air may be kept constant when driven by the motor. What is commonly known as "volplaning"—descending from a height without the motor, is simply a succession of these dives, followed by alternate periods of sailing on an even keel or at a slight upward angle.

There are two different principles by which inherent lateral stability is secured. The first of these is simply to arrange the main supporting surfaces at a dihedral angle, or to use vertical surfaces, *i.e.*, fins or keels, with a low center of gravity. Both of these constructions give the same result, viz, the air pressure on the lower side is increased, thus causing it to rise. The other method is somewhat more complicated for, in this case, there must be a vertical plane at some distance behind the center of gravity. If, with this arrangement, the aeroplane tilts to one side, it will slide sideways until the air catches the vertical plane in the rear and turns it head into the wind. The result is that instead of upsetting, the aeroplane simply wings around. If there be a constant upsetting force, however, the radius of the circle becomes smaller and smaller and, unless corrected by the controlling planes, the machine strikes the ground banked at a steep angle. But this principle works fairly well even in high winds and is employed on the majority of successful aeroplanes. A typical instance of its use is found in the Antoinette monoplane in which a large vertical surface is combined with a triangular elevator at the extreme end of a long tail frame or fuselage.

However, though an aeroplane may maintain its balance in still air in this manner, when winds arise troubles arise with them and for that reason the beginner is always cautioned never to attempt a flight in a power-driven machine except when there is an absolute calm. Since the stability of the machine depends upon the reaction of the air upon it when gravity pulls it one way or the other, the balance is disturbed whenever it is struck by wind gusts. For instance, just as when the aeroplane flies too rapidly through the air it turns upward until its velocity decreases, so if a wind strikes it in front its speed through the air is increased and the front turns up and if the wind comes from behind its speed is decreased and it turns toward the ground. If the wind gust is sharp and the aviator is flying low, he may strike the ground before equilibrium can be recovered, and not a few aviators have either been seriously injured or killed in this manner, it being thought that a condition of this nature was responsible for the death of Moisant whose machine suddenly plunged to the earth from a height of only one hundred feet.

It has been determined by innumerable experiments with every type of model, that, in general, the closer the centers of gravity and pressure coincide, the less the longitudinal stability is influenced by variable air currents. It is almost impossible for a well-balanced aeroplane to be completely overturned while in the air, but it may easily be tipped to an angle which is very dangerous, especially when close to the ground. This method of obtaining stability is the only one in common use up to the present, but it has been noted that while it works very well in calm air, it may become a source of danger rather than of safety when used in gusty winds. If every time the aviator comes within one hundred feet or less of the earth he is in danger of being dashed precipitately to the ground, the aeroplane can scarcely be considered a practical or safe machine. As has already been noted, the designers of successful machines have provided ample area in the stabilizing surfaces to counteract extremes of movement of the center of pressure caused by variations of wind velocity and direction, so that if it be possible in any manner to cause these balancing planes to act of their own accord to counteract changing conditions as rapidly as they arise, perfect equilibrium in the most sharply varying winds will be attained. This in brief is the problem of automatic stability.

AUTOMATIC STABILITY

As at present constituted the lateral stability of an aeroplane is largely dependent upon the aviator himself. That it is precarious at best is amply evidenced by the numerous fatalities among skilled aviators, many of which have undoubtedly resulted from inability to think quickly enough—to always do the right thing at the right moment. Control once lost is apparently lost for good, if the numerous disastrous plunges to the ground from varying heights that have followed loss of control, may be regarded as a criterion. To obtain this control by mechanical means, independent of the skill and dexterity of the aviator, is accordingly one of the most generally sought improvements in the aeroplane today.

Before describing some of the more important devices put forward to attain this end, it is essential that a clear understanding of what is meant by the term "automatic stability" be had, as it is very generally confused with "inherent stability." Any stabilizing effect brought about by the shape of the planes or the addition of keels, as represented by the numerous vertical partitions between the main planes of the first Voisin types, is merely inherent stability. This is due to the form of the machine itself, *i. e.* to the employment of extra surfaces in a certain way, so that the machine has a natural tendency to right itself and maintain an even keel in flight. This is often erroneously referred to as automatic stability, whereas the latter, in the real sense of the term, can be accomplished only by some extraneous device designed mechanically to counteract the adverse effects of the wind.

PRINCIPLES OF CONTROL

Balancing is, of course, automatic in the case of a bird and the method employed by the bird may possibly be imitated. The organs by which equilibrium is maintained are known as the semicircular canals. They are small, hair-like tubes filled with fluid lying in three planes at right angles to one another in the bone of the skull, each tube controlling through delicate nerve-ends the movements of the bird in its respective plane. Although it is not possible to reproduce artificially such a complex and delicate structure, devices designed to act in much the same manner may be employed.

Controllers employed to regulate the supplementary surfaces in this manner may be divided into three general classes: (1) Those which depend for their balancing properties upon the action of the air itself when the position of the aeroplane is altered; (2) those depending upon the action of gravity, such as pendulums; and (3) those depending upon some other force than gravity or the reaction of the air to control the balancing planes.

Air Reaction Principle. The most simple form of controller depending upon the reaction of the air is that in which longitudinal stability is regulated by an auxiliary vertical plane struck by the wind in front, and lateral stability is regulated by a plane acted upon by air currents from either side, as shown in Fig. 12. In this case, when the aeroplane turns down, the increased speed increases the pressure on the wind plane *A* and, forcing it back, elevates the horizontal rudder, or elevating plane. If it turn up, the pressure diminishes and the spring *B* brings the plane forward and depresses the rudder. If the aeroplane tilt to one side, it slides down edgewise until sufficient pressure results on the surface *C* to cause the latter to adjust the ailerons or warping edges of the wings to counteract this effect. The faults of this type of automatic control are obvious. Since the action of the balancing planes depends entirely upon the wind striking the controlling surfaces, the result of sudden gusts is to greatly disturb the stability of the machine. In fact, it is made much more sensitive to suddenly changing conditions than the machine which secures stable equilibrium by means of fixed supplementary surfaces as already described.

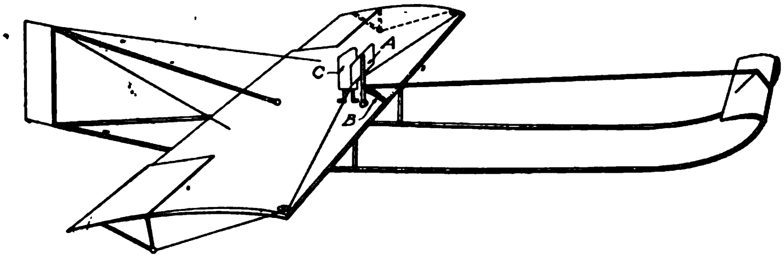

Fig. 12. Stability Control by Auxiliary Planes

Longitudinal Stability Control. To eliminate this trouble with wind gusts, the Wright Brothers invented an automatic controller of longitudinal stability designed to maintain the aeroplane flying at a definite angle of incidence instead of at a constant velocity through the air. The principle of this automatic control is shown in Fig. 13, with, however, the omission of compressed-air connections to set the horizontal rudder according to the position of the controller. The regulating plane A_1 is placed parallel to the plane of flight, and is connected by levers and rods with the elevator *L*. Whenever the aeroplane turns up, the wind strikes the under side of A_1 moving it to A_2 and depressing the rudder, or *vice versa*. It will be apparent that this device is likewise influenced by wind gusts but not so

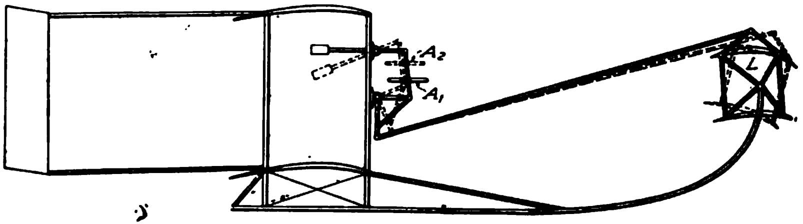

Fig. 13. Diagram of Wright Automatic Stabiliser without Compressed-Air Connections

strongly as the type just mentioned previously, though when flying close to the ground it would probably be as dangerous as the usual manual control, should the machine be suddenly struck from behind by a strong gust of wind. It has been employed in experimental flights but the Wrights state that they can not trust it as fully as they can their own skill in maintaining the equilibrium of the machine in gusty winds.

Wright Brothers' Patent. The Wright Brothers were awarded a patent in England, in 1909, on this device (No. 2913-1909). It is described as follows:

> Using compressed air or other fluid pressure as power, the action of the contrivance is controlled in one case by a pivoted vane acting under the influence of the wind; in the other case by a pendulum. In both cases the controller is merely used to operate a three-way valve, its influence upon the manipulation of the steering gear or front control (old Wright machine), as the case may be, taking place through the agency of a relay which the opening of the valve brings into action.
>
> This relay mechanism consists of a compressed-air engine which is linked up to the steering gear or front control, as the case may be, by means of a connecting rod. The engine itself is operated by compressed air from a reservoir, which would presumably be maintained or kept charged by a pump attached to the aeroplane motor. Regarding the compressed-air system as the principle, the patent covers two separate and distinct applications to the same flyer. One of these systems is exclusively devoted to the control of the elevator, *i. e.*, the front horizontal control. The other is likewise reserved solely for the manipulation of the vertical rudder and the warping of the main planes. Each of these systems has its own reservoir, or compressed-air tank, engine, and controller, the latter apparatus being, as already mentioned, a pivoted vane in the case of the elevating gear, and a pendulum in the other instance.
>
> The apparatus consists of a pulley normally under the control of the aviator through the agency of a lever, but embodies such features in its construction as enable it to be coupled up to the connecting rod of the engine which is operated from the tank of compressed air. There are two connections from this tank to the cylinder of the engine, the one to the lower part of the cylinder being permanent, while that to the upper first leads to the three-way valve designed to be operated by the automatic movements of a horizontal vane, or aeroplane, mounted on an arrangement of beams forming a parallel motion mechanism. The frame upon which these beams are pivoted hangs from brackets mounted on an adjacent part of the main struts of the flyer, and one of its members is prolonged downward to form a handle within reach of the aviator.
>
> The advantage of this arrangement is that the pilot himself may reset the course, or, as it may be better described, "the neutral line of flight;" *i. e.*, if, after having flown along a horizontal course, it is desired to ascend, the automatic mechanism may still be retained in action to guard the machine against variations from its ascending path by merely resetting the position of the frame. Since the three-way valve is mounted upon the frame and because the beams

are independently in equilibrium as a whole by reason of the balance weight, it will be evident that any alteration in the position of the frame will at once affect the state of the valve; *i.e.*, if open, it may tend to close it, or *vice versa*. Assume it to be open and the elevator set for ascent, then should the pilot wish to ascend permanently, he will move the handle so as to open the valve a little way. This will have no effect directly upon the position of the controlling vane because the balance weight serves to keep it horizontal irrespective of the position of the frame. The change from a horizontal to an ascending flight path, however, will automatically result in a change of the real altitude of the vane to the relative wind, which will now bear upon it partly from above, and will thus cause it, when the wind is strong enough, to fall a little and close the valve. This action will bring the relay mechanism into action and will alter the angle of the elevator until the conditions are restored, which will cause the controlling vane to return to its normal position. Naturally, these appliances are not dead beat and, consequently, oscillations are set up which require time to die out and it is more than likely that the normal state of affairs would be one in which the vane is constantly moving up and down.

For regulating the lateral stability, a pendulum is employed instead of a vane, the pendulum being suitably coupled to the valve so that any canting of the flyer from its normal level causes the valve to open or shut according to the requirements. The pendulum hangs straight down like a plumb bob under the influence of gravity and it is thus really the movements of the machine as a whole about the pendulum as a fixed point which form the control. In practice, the normal state of the pendulum control would presumably be one of more or less continuous, though possibly slight, oscillations. In the same way that it is possible for the vane to alter the neutral line, so can the same variation be accomplished with the pendulum, and, if necessary, the flyer be made to travel in a circular path indefinitely.

Regarding this patent, Orville Wright stated in an interview at the time of its granting:

> The device which the English are making such a fuss about is an old contrivance with which we planned to get automatic stability as long as five or six years ago. That was before anybody believed that flying as we know it today was possible. Since then we have progressed beyond this device and have others which may be great improvements. The vane and pendulum device is a very simple one. It can be adjusted to any machine in a few minutes and, theoretically, it works very well. We have used it often but I do not think it was used in connection with any big flights. Since first bringing it out, we have been working upon several devices to obtain automatic stability. We realize that if we can make an aeroplane balance automatically in the air while in flight, it will be a very important step forward.

It is accordingly apparent that a wind plane is not an entirely practical device to employ as a controller either in a horizontal or a vertical position when used in either of the ways just outlined, or in any manner partaking of the characteristics of these methods. Consequently, this eliminates all devices in that class for the time being, and the value of the pendulum, as being the chief representative of the class depending upon gravity for its action, may be considered.

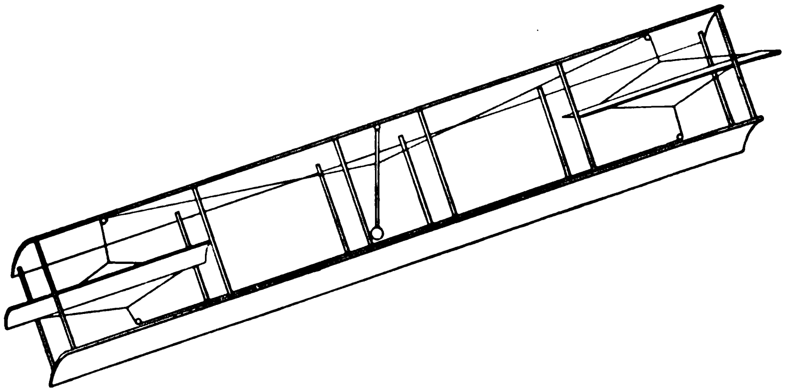

Fig. 14. Diagram Illustrating the Fault of Pendulum Control

Gravity Principle. The effect to be gained by the use of this, as illustrated in Fig. 14, is that, when the aeroplane changes its position with respect to the direction of the force of gravity, the pendulum will remain vertical, and either by direct connections or by operating valves for compressed air or by making contacts which will set electrical devices in action, it will reset the balancing planes so as to re-establish the equilibrium of the machine. This is excellent in theory and many have accepted the latter blindly, but one great difficulty is that under the influence of sudden gusts the pendulum is likely to oscillate so violently as to destroy all stability. This is not insurmountable, however, as these oscillations can be damped by friction or a water bath or a mercury level, as shown in Fig. 15. But even if these oscillations be reduced to a negligible point, the pendulum when used as a controller does not preserve a vertical position except by the reaction of the air upon the aeroplane, and, therefore, can not be successfully used. This is illustrated by Fig. 16. If the aeroplane be tipped at an angle N, there is an acceleration due to gravity tending to bring the pendulum back to a vertical position, which is evidently equal to $g \sin N$. But supposing

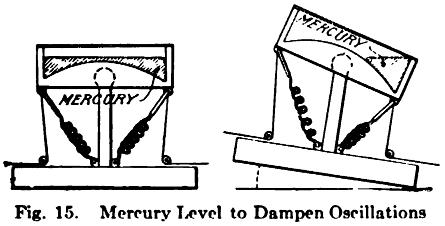

Fig. 15. Mercury Level to Dampen Oscillations

the resistance of the aeroplane to motion in a horizontal plane to be zero, when tipped at an angle of N degrees its acceleration is also $g \sin N$, the same as that of the pendulum. This being the case, there is no force to change the latter's position with reference to the former. If, however, as is always the case, the aeroplane offers some resistance to motion in a horizontal direction, as its speed through the air under the influence of gravity is increased, the resistance will increase and its acceleration will correspondingly diminish. The controller will then resume its perpendicular position and by means of its connections adjust the balance of the machine. But here the former difficulty again enters. If it is only because of the air resistance that the air controller works, it will be affected by wind currents. For instance, if a sharp gust of wind should strike the machine from one side, it would blow the wings over, while the pendulum, owing to its inertia, would tend to remain in its original position, and would therefore swing toward the wind, raising the aeroplane on that side. In fact, so many have pinned their faith to the pendulum, and still do—purely on theoretical grounds—that a resumé of the manner in which it acts under all conditions will be of value in demonstrating the futility of further attempts along this line. This, of course, refers to the use of a pendulum as a direct agency in operating the controls to give automatic stability, and not to a small pendulum employed as a relay to set a motor in operation, as in the Wright device. However, the same objections would be present in the latter device, though on a greatly reduced scale.

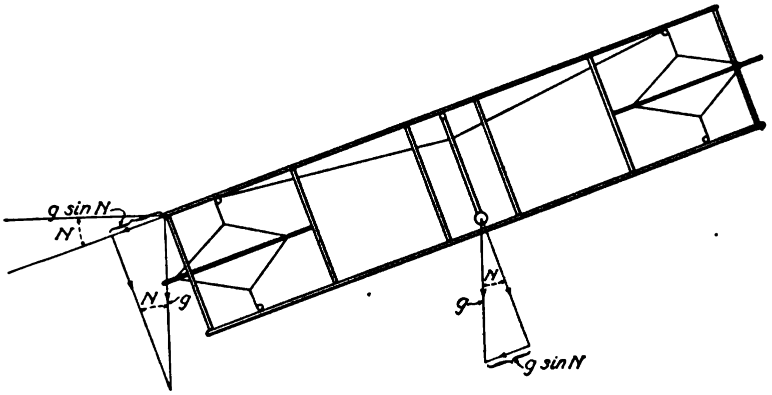

Fig. 16. Theoretical Diagram of Action of Pendulum Control

The manner in which a pendulum device is relied upon to give automatic control is best shown by reference to Figs. 17, 18, and 19. Fig. 17 represents a longitudinal section of a pendulum control *P* for fore-and-aft balance, and an elevator rudder *E*. The direction of flight is indicated by the arrow and in this same diagram the aeroplane is assumed to be in normal, horizontal flight. Fig. 18 shows the same apparatus immediately after a sudden gust has tilted the front of the machine up. The pendulum *P*, due to its inertia, has retained its vertical position *P'*, but in doing so has pulled on the rod *ab*, causing the front elevator to assume the position *E'* and to receive the pressure of the wind on its upper face. This causes a downward force on the rudder surface which brings

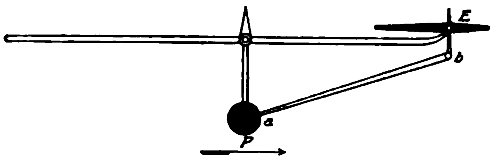

Fig. 17. Pendulum Control. Machine Going Steadily

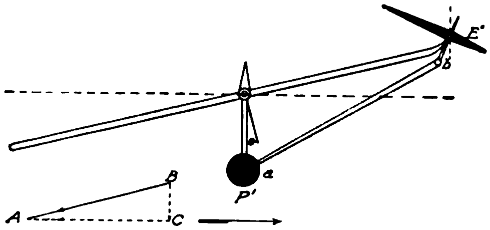

Fig. 18. Pendulum Control. Restoring Action when Machine Rears

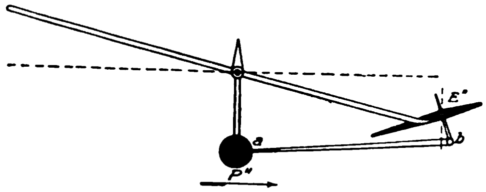

Fig. 19. Pendulum Control. Restoring Action when Machine Dips

the machine back to the horizontal. Fig. 19 represents the effect of a sudden downward plunge of the machine.

In the same manner, the inertia of the pendulum is used to move side controls when a sudden transverse tilt occurs. Of course, the nature of the pendulum and the manner in which it controls the equilibrium is vastly different in many of the suggested methods, but the fundamental principle is always the same, the pendulum itself consisting variously of an extra weight, the weight of the car, the weight of the aviator swinging on a movable seat, or the movement of a mercury bath.

Objections to Pendulum Devices. There are four distinct objections to employing any kind of a pendulum device for automatic stability:

(1) The most important objection is that, if the pendulum is at all heavy, it will tend when the machine is tilted to accentuate greatly the tipping. Thus, in Fig. 18, due to the fact that the weight P' has traveled through an angle θ, with respect to the frame, there will be a strong downward pull in the direction BA. This will certainly accentuate the downward force at the rear, due to the vertically downward component BC. If the weight is heavy enough, and the inclination great enough, this is likely to completely unbalance the machine.

(2) Another effect upon a pendulum mechanism that makes it distinctly undesirable is that if there is a sudden lurch of the entire machine, either forward or backward or to either side, unaccompanied by any tilting, then the inertia of the pendulum will cause it to swing away from the side to which the machine lurches, thus moving the rudder and actually disturbing the equilibrium of the machine, by either making it rise, plunge, or tilt over to one side. Due to "holes in the air," sudden side gusts, and even variable propeller thrusts, such sudden lurches are of more or less frequent occurrence and unless some means of deadening the pendulum is provided the equilibrium will be very unstable.

(3) The action of centrifugal force in making a turn will cause the pendulum to assume a position parallel to the struts of the machine, or of any other normally vertical parts, and it will not fly to the outside as is commonly supposed. Its action in turning, therefore, is nil, and to make the turn positive it would be necessary to

install a separate control. This arrangement assumes a proper "banking" of the machine.

(4) After any displacement of the pendulum itself from its normal position due to the sudden movement or lurch of the aeroplane, the pendulum will at once tend to swing back to the normal. If the period of this swing should just happen to coincide with the frequency of any vibration or sway in the machine or with any wave pulsations of the air stream, then the swinging would continue and be amplified, eventually destroying the equilibrium of the machine. Synchronism of this sort is not at all unlikely to happen for air waves are known to possess pulsations at regular time intervals; and in addition, propellers have often been found to give continuously and rhythmically varying thrusts, causing a slow swaying vibration in the aeroplane quite distinct from the vibration of the motor.

It appears, therefore, that the use of a pendulum for preserving the lateral stability of an aeroplane is limited in its action to the condition of comparatively steady, horizontal flight, and is hardly feasible in very gusty weather. A pendulum device, designed to act as a relay, setting in operation an electrical apparatus which causes an increase or decrease in the thrust of the screws of a four-propeller type of helicopter machine, was patented in this country as far back as 1888, and many others of a similar nature have been patented since.

All of the foregoing, however, is to a very large extent based upon the theory of the pendulum's action under the varying conditions in question, and is merely the result of the author's study of this phase of the subject from a theoretical point of view. That the conclusions reached are not well substantiated in practice will be evident from the following excerpt from a letter written by Orville Wright to the author, calling attention to the fact that his experience with the pendulum was quite to the contrary. He says:

> We have always considered a pendulum theoretically an almost perfect system for lateral balance. If the vertical rudder of a flying machine is turned so as to face the machine towards the left, the momentum or centrifugal force of the pendulum will cause it to swing to the right-hand side. This will cause the wings to be warped until the machine is banked enough to bring the pendulum at right angles to the planes, which is exactly the bank the planes should

take in making a turn. Not only is this theoretically the case, but in all of our experiments with our lateral stabilizing device this fact has been conclusively demonstrated.

There are pendulum-operated stabilizing devices in use in which it is necessary for the operator to make adjustments in order to give the machine a proper bank in turning, but this is not due to a fault of the pendulum but to other devices which have been incorporated with the pendulum in the stabilizing system. The Ellsworth lateral stabilizer is one of this type. Theoretically it would operate only in straight flight and could not make a turn without special adjustments by the operator. I have recently made some flights with a new lateral stabilizing device, in which the pendulum is used and, by simply setting the top lever of our machine slightly to one side, the device banks the machine for turning and holds it at the proper bank without any assistance from the operator. The fact that the pendulum does give a proper bank to a machine in making a turn, I consider to be its principal virtue. For theoretical reasons I have always considered gyroscopic devices inefficient for fore-and-aft control. I hold to the theory that true stabilizing devices should be dependent on the wind. Assuming a case where a machine is flying with the least power that can possibly sustain it at its most favorable angle of incidence, any device that operates purely with reference to the vertical or horizontal, will cause it to fly at a different angle in case it runs into a rising or descending trend.

I also noticed some reference to an automatic device, which I took with me and was intending to try at Kitty Hawk (October, 1911, experiments). This was an automatic device for fore-and-aft equilibrium, and is not the one described in our patent of several years ago. I did not try it on account of the presence of the newspaper men at Kitty Hawk. I have had one of the power machines here equipped with the device, and expect very soon to test it out thoroughly.

AUTOMATIC STABILIZERS

Eteve Stabilizer. A number of experiments have been made with devices designed to give automatic longitudinal stability alone, one of these—the invention of Captain Eteve, of the Sapper balloonist battalion of the French army—having been put to numerous tests in actual practice. The machine itself was a Wright biplane of French construction, the usual rear rudder of the original Wright type of machine being replaced by two hexagonal planes borne on a special stabilizer framework and controlled by spring-held cables. As shown by the sketch, Fig. 20, the two planes *A* and *B* are movable on the axis *E*, the latter being carried by a framework about 15 feet long, attached to the transverse members of the aeroplane surfaces. A horizontal vane *D*, movable on an axis *F*, is connected to the planes *A* and *B* by rods *KJ* and *KL*. The axis of the vane is firmly fixed to a tube *H*, controlled by the rod *MI* through a bell crank, *MHF*, this rod being in turn operated by a lever maneuvered by the pilot.

When the lever is fixed, axis *F* is immovable and the stabilizer vane struck by the wind moves sensibly in the belt or layer of wind immobilizing the planes *A* and *B*, which are compensated; the angle of attack of these planes is then invariable when the direction of the air current is constant, Fig. 21A. But when this latter varies, the movement of the vane is modified and the planes *A* and *B* turn in a direction contrary to that of the vane.

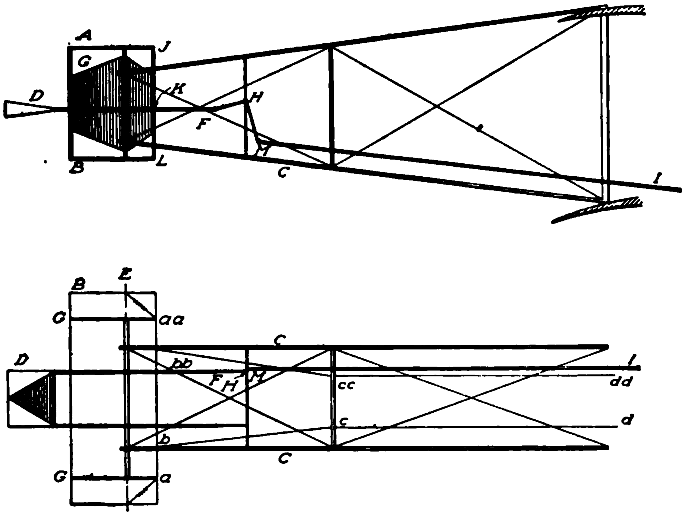

Fig. 20. Detail Diagrams of Eteve Stabilizer

Should the aeroplane "rear," Fig 21B, the vane *D* is tilted and causes the planes *A* and *B* to turn in a direction contrary to their proper movement. This tends to correct or straighten out the aeroplane; when it "plunges," Fig 21C, the reverse effect is produced and the maneuver is executed without interference owing to the simplicity of the mechanism, a quality indispensable to an automatic stabilizer. It will be noted that the Eteve device does not depend upon any external source of power but is operated by the action of the wind itself.

The planes *A* and *B*, considered as depression rudders, automatically partake of the same movements as those resulting from the maneuver made by the pilot; moreover, the vane has the advantage over the aviator of acting simultaneously with the cause that produces the disturbance of equilibrium. In a word, the Eteve stabilizer opposes all variations of the angle of attack of the aeroplane in the same manner as a very long, light, and instantaneously-acting *empennage* (tail) would. Of course, it is necessary to be able to vary the magnitude of the angle of attack in order to climb or descend. To preserve the automatic action of the stabilizer prior to, during, and after the execution of the maneuver by the pilot, the axis *F* of the vane can be raised or lowered by means of a lever under the control of the aviator, as in the Wright apparatus already described. All displacement of *F* involves a change of equilibrium of the vane and consequently a modification of the angle of attack of the planes *A* and *B*. (Note positions *D* and *E*, Fig. 21.) This indirect control of the stabilizer offers the great advantage of rendering the vane sensitive to exterior influences, the apparatus playing the role of depression rudder and stabilizer at the same time.

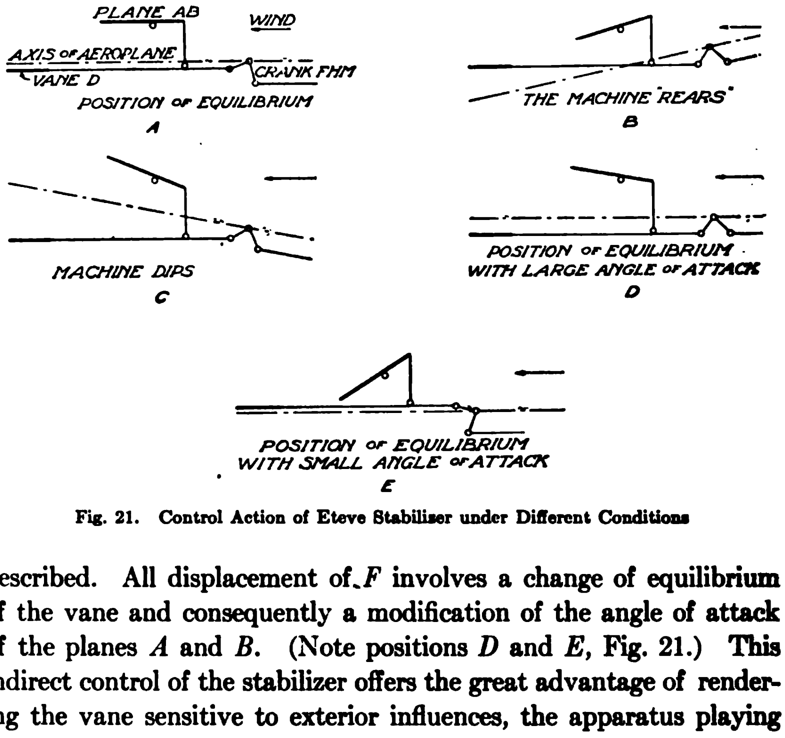

Fig. 21. Control Action of Eteve Stabilizer under Different Conditions

The weight of the entire stabilizer tail is 60.5 pounds, which, less the vertical rudder it displaces, only places an additional weight of 26.5 pounds on the machine. The total surface of the stabilizer planes is 43 square feet, or half the surface of the depression rudder of the Wright aeroplane. The numerous experimental flights made with the machine thus fitted demonstrated the important rôle played by the stabilizer. First, preliminary attempts were made to verify the equilibrium of the modified aeroplane, the operation of the apparatus then being tried out by running on the ground. Next, flights of a quarter to half a mile with turns were made; then a flight of 10 minutes was made which showed that the ordinary Wright machine can be thus readily controlled. The operation of the depression rudder was found to be considerably simplified, and despite the large surface of the depression rudder of the Wright machine, the stability was such that the apparatus frequently remained in equilibrium for some minutes without the intervention of the aviator.

Gyroscopic Stabilizers. The consideration of the different types of automatic controllers already discussed leads to a conclusion which is almost self-evident. The same cause always produces the same result and hence, when an aeroplane is tipped to one side, if it is turned back to its proper level by the action of the air due to its change of velocity or angle of flight through the air in that direction, then, when an equal change in angle of flight or speed through the air is caused by some gust striking the machine, the aeroplane will be affected in a similar manner. For instance, when an aeroplane in stable equilibrium turns upward, its speed through the air is diminished and the front drops to the proper level, but when a wind strikes it from behind, its speed through the air is likewise diminished and the front will again drop, but this time away from the proper angle of flight. Therefore, since it is found that the stability of all machines balanced in a manner similar to those above described must depend upon the machine's reaction with the air, no such system of automatic equilibrium can be depended upon to preserve perfect balance while the aeroplane sails through the currents and cross currents met with in practically every flight.

True Stabilizer Independent of Wind Changes. It is essential, therefore, that the controller shall be sensitive not to the force or direction of the wind that strikes the machine, but to some other force which will move the controller with respect to the aeroplane when its equilibrium is disturbed. The only such forces known are that of the earth's magnetic field acting on a magnetic needle, and the gyroscopic force of a rapidly rotating wheel. The magnetic needle is usually employed merely to indicate the north, but since the earth's magnetic field tends to make it dip downward at an angle of about 75 degrees with the horizon, and since this angle is constant in any locality, if the direction of flight be fixed, the magnet may be employed to determine a horizontal position. It may be made to operate the controlling planes through the medium of electromagnets acting to open and close the valves of a compressed-air motor. Since both arms of the magnet have the same mass, neither gravity nor centrifugal force, due to the oscillations of the aeroplane, would affect it in any way, but the slightest vibration once started would continue indefinitely and thus be transmitted to the control of the aeroplane. Also in making turns, since the needle points downward at an angle of 75 degrees, instead of 90 degrees, there would be danger of losing balance. So, aside from the prohibitive frailness of the construction, the magnetic needle would not make a suitable controlling device. It is therefore necessary to examine what can be accomplished with the aid of the gyroscope.

Gyroscopic Action. It is a well-known fact that a rapidly spinning top forcibly resists any attempt to change its plane of rotation. This force depends upon the weight at the periphery of the revolving body and its speed of rotation. The top is a gyroscope in its simplest form, and by giving it the form of a flywheel with a heavy rim we have the toy that is doubtless familiar to most boys—the gyroscopic top. In this, the diminutive flywheel is supported on a spindle carried in a circle of wire in order to provide a means of support independent of the spindle itself. When spinning rapidly, such a top will continue to rotate in any plane in which it is placed, horizontally, vertically, or at any angle between the two. This singularly curious force was first applied industrially in 1870. Since then the progress achieved in its use has been comparatively slow. It has been employed for securing much-needed stability to the Beauchamp hydraulic turret, the Obry torpedo, the Scherl, Brennan, and Froelich monorail systems of transportation, and to Schlick's device for preventing the rolling of a ship.

Widespread interest now attaches to its employment in a similar rôle on the aeroplane. In this connection, however, the distinction between equilibrium and stability should be borne in mind as the terms are so frequently used interchangeably as to prove confusing.

Briefly stated, an aeroplane is in equilibrium when traveling at a uniform rate of speed, and it is necessary for stability that, if the aeroplane is not in equilibrium and be not moving uniformly, it shall tend toward a center of equilibrium, also that any oscillatory motion shall have a positive coefficient of subsidence. A thorough study of the different forms of machines made by a close observer led him to the conclusion that the only two types likely to prove stable under ordinary conditions are the single-surface glider and the balanced glider. The first, as he expressed it, relies for its longitudinal stability on the variation of the center of pressure with the angle of attack, while the second relies on the variation in altitude of a balancer or tail surface. In each case, a torque should come into existence to bring the glider back to its original position. With these types, however, as they now stand, a very severe squall is likely to prove disastrous; for the righting of the machine can not be made rapidly enough. There must necessarily be an automatic adjustment to secure the equilibrium of all the planes.

Regnard Device. To bring about this automatic adjustment, numerous inventors are looking to the gyroscope as a solution of the problem, one of the first machines to be equipped with it being the Regnard monoplane. The details of the aeroplane in plan and elevation are shown in Fig. 22, while the gyroscope and its mounting are given in Fig. 23. In this case, the small and comparatively light gyroscope used is not directly employed to insure stability. It merely serves to transmit an electrical current to devices for giving both lateral and longitudinal stability. The gyroscope itself, *A*, Fig. 22, is located directly beneath the center of the main supporting surface *I* and in line with the motor. It is hung on gimbals—*i.e.*, a universally-jointed support, Fig. 23, permitting complete independence and freedom of movement. Within the ring *A* of this gyroscope is the flywheel *T* and the ring armature *C* of a small electric motor to which it is directly coupled at its lower end.

The stationary field *L* of the motor is also of the ring type and lies in the same plane as the armature it encloses. Current from eight or ten storage cells of about the size ordinarily employed in electric vehicles, maintains the flywheel in rotation at a speed of 10,000 r. p. m. According to well-known laws of mechanics, it will adopt under the influence of this rotative speed an invariable plane, parallel to the plane of the space wherein it is hung—a horizontal plane in this case. Owing to its method of support it will take, with reference to the aeroplane, all the relative positions corresponding to the inclination of the latter. In other words, the gyroscope will

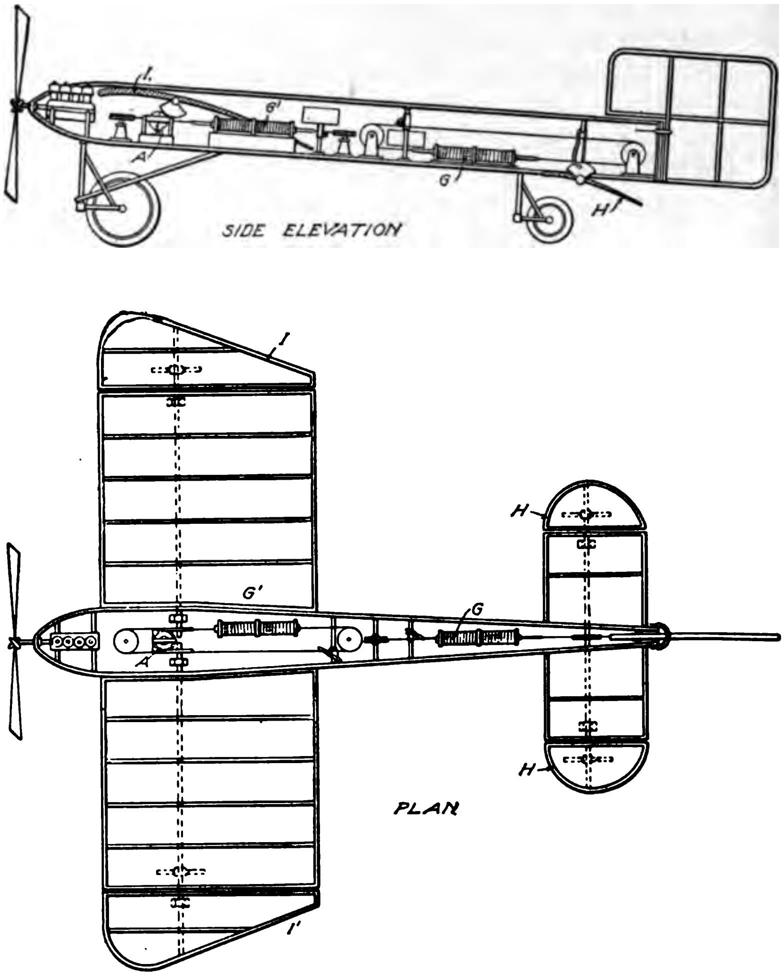

Fig. 22. Detail Diagrams of Regnard Gyroscopic Stabiliser

continue to revolve in its horizontal plane, while its frame, attached to the aeroplane, will assume different positions relative to it in accordance with the angle of inclination of the machine, *i.e.*, the gyroscope remains stationary while its support moves about it as a fixed point. In doing so, the stud E, rigidly attached to the gyroscope, establishes electric contact with the plates F, according to the movements of the aeroplane. Each of these contacts is alternately employed for controlling and steadying the movements of one or more of the surfaces of the aeroplane.

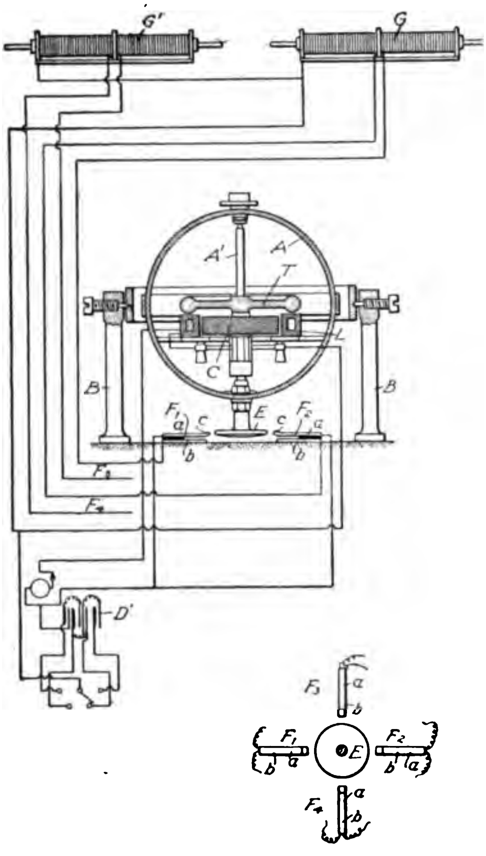

Fig. 23. Gyroscopic Control-Device of Regnard Stabilizer

These contacts can be made in a number of different ways—by way of example, as shown in the upper and lower diagrams of Fig. 23, through the medium of the conducting plates a and b, which are superposed but not touching. The upper plate a has a projection c on which the stud E will press, the convex surface of the latter always corresponding to the center of rotation of the gyroscope. Regardless of the inclination of the aeroplane the axis of E is always vertical, and in whatever direction the machine cants, it will press momentarily upon the plate a, the latter then coming in contact with b. The circuit thus established can be utilized for specially controlling any one or more of the balancing organs of the aeroplane. In the present instance, this is effected by means of solenoids, or hollow electromagnets, in which soft iron plungers slide. Two of these solenoids, G and G', are employed, adapted to be energized in alternate directions by means of two sets of contacts, F_1 and F_2, for the longitudinal balance, and F_3 and

F_4 for the lateral balance. For instance, should a strong gust of wind cause the aeroplane to tilt downward, E will instantly make contact with F_1, energizing the solenoid G. The plunger of the latter is suitably connected by means of a cable to the elevating rudder H and the pull exerted by the solenoid will vary its angle of attack downward, thus righting the machine, or bringing it to an even keel. In case of the reverse inclination—the tendency of the aeroplane to stand on its tail—the solenoid G will again come into action through the contact F_2, but the plunger will move in the other direction due to a reversal of the current, and the elevating rudder will be moved to the opposite angle, again bringing the machine down to an even keel, or horizontal plane. Transverse control is maintained in a similar manner, an inclination to either side causing the solenoid G' to come into action in one direction or the other through the contacts F_3 and F_4, according to the movement of the aeroplane itself. The plunger of this solenoid is connected through suitable multiplying gear and cables to the warping apparatus of the wings.

It will be noted that this device is practically similar in its operation to the Wright apparatus, except that a gyroscope is employed as an automatic governing control in place of the vane and pendulum of the latter, and electric power is employed instead of compressed air. In other words, both devices merely relieve the aviator of the constant necessity of manually operating the usual controls for maintaining longitudinal and lateral stability—the elevating rudder and the wing-warping levers. There is nothing unusual about the Regnard apparatus electrically or mechanically, except the automatic method of making contact by means of the gyroscope, the action of a solenoid being commonly utilized to operate such electrical apparatus as circuit breakers and the like. However, the efficiency of a solenoid is comparatively low; it requires considerable current to cause it to generate an appreciable amount of power and to act quickly. With such a limited source of power as the storage cells mentioned, the solenoids would have to be prohibitively heavy. Of course, a dynamo could be run by the motor of the aeroplane itself, but this likewise involves considerable extra weight. Moreover, while an apparatus such as that described would be considered simple for an electric lighting station or similar installation, it involves an excessive amount of complication for an aeroplane—there would be entirely too many small things to look after and keep in order. Using a generator directly attached to the gasoline motor and two small electric motors instead of the solenoids, would simplify the apparatus somewhat and make it much more powerful for its weight, but still there would be entirely too much unnecessary weight to carry along. The attempt is interesting as illustrating what may be done, but there are doubtless few aviators who would not prefer to rely upon their skill in manually operating the controls rather than have the machine encumbered with so much apparatus, particularly as some means of cutting out its action when desiring to ascend or descend would also have to be provided, as mentioned in connection with both the Wright and Eteve stabilizing devices.

Beach Device. Utilizing the controlling force of the gyroscope direct would appear to hold forth much greater promise of simplicity and reliability in action. This was attempted during 1910 by an American, Stanley Y. Beach, the aeronautical editor of the *Scientific American.* The gyroscope in this case is a flywheel weighing about 20 pounds and is designed to revolve in a vacuum at 10,000 r.p.m. The complete apparatus weighs about 30 pounds. The gyroscope itself is illustrated in Fig. 24, while its location and method of attachment to a Beach monoplane (Bleriot type) is shown at the bottom of Fig. 25. The flywheel is driven through bevel gears so that it runs about three times as fast as the driving pulley on the horizontal shaft. The spindle projecting out at the top, Fig. 24, passes down through a long bushing about 6 inches in length and drives a short shaft at the bottom through a ratchet attachment. It is in fact, a friction drive, the details of which are not as yet protected by patents, for which reason they are not given here.

To obtain the vacuum, which makes necessary only a fraction of a horse-power to drive the flywheel, a small vacuum pump, about the size of the ordinary bicycle pump, is attached by means of a short rubber tube to a pet cock at the apex of the conical housing. The air can be exhausted from this housing with the pump in question in about five minutes, and the leakage about the stuffing box of the spindle is so slight that the vacuum is maintained for almost twenty-four hours. The only object of employing a vacuum is to minimize the amount of driving power necessary, it having no effect one way or the other upon the gyroscope or its action. When driven in the air, two or three times as much power is required and it takes a great deal longer to get the flywheel up to speed owing to the resistance. With a vacuum, on the other hand, only about fifteen minutes are necessary for it to attain a speed of 10,000 r.p.m. and it will then continue to run for one and a half to two hours without any further application of power.

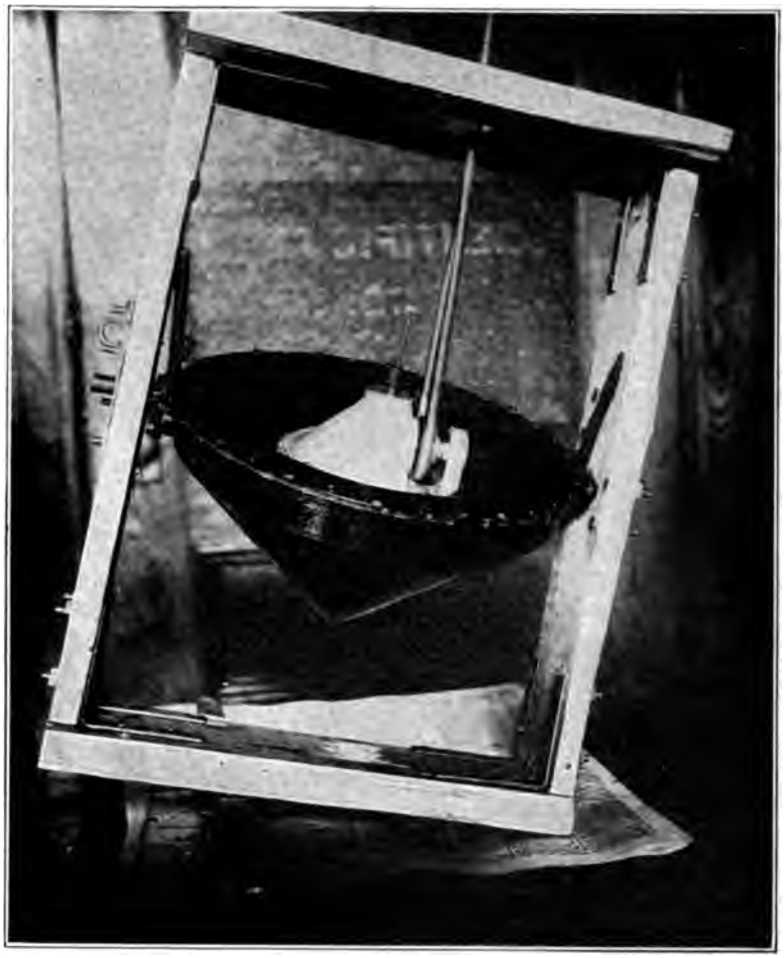

Fig. 24. Beach Gyroscopic Stabiliser

When the aeroplane tends to tilt to either side, the gyroscope will resist this inclination with a force of 900 pounds at a distance of 1 foot from the center of the flywheel. At the same time, as the aeroplane inclines slightly to one side or the other, the gyroscope will tilt forward or backward, as the case may be. To permit of overcoming this force of the gyroscope, when not desired, a band brake acting on a drum on the shaft (not shown in the illustration) is employed. This locks the gyroscope and prevents its performing its act of *precession,* as it is technically termed. In this condition its resistance is practically negligible and applying this brake allows the aeroplane to "bank" in rounding a turn by means of the transverse warping control as is customarily done. Should the aviator neglect to apply this brake before attempting to make a turn, however, no harm will result, as the machine will then simply remain on a level keel and "skid" or slide toward the outer circumference of the curve it is making, under the action of centrifugal force. Fig. 24 shows the complete gyroscope mounted in a frame corresponding to its support on the aeroplane, this frame being tipped to represent the inclination of the flyer to the right. It is being driven at its usual high speed as shown here and the forward tilt of the apparatus is noticeable, though this does not appear to

Fig. 25. Beach Gyroscopic Stabilizer Mounted in an Aeroplane Frame

be as great as it is in reality. When tried on a monoplane running over the ground, this gyroscope gave a perceptibly steadying effect, though not running at more than half its normal speed.

Doutre Stabilizer. This is a type that differs more or less radically from any of those already mentioned. It has been put to severe tests by the army in both France and Russia and has showed unusually promising results. The apparatus consists of two elements, each fulfilling a distinct function. The first of these is, properly speaking, an anemometer whose purpose is to detect changes in the wind pressure; the second element constitutes an accelerometer, its function being to detect and respond to changes in the velocity of the aeroplane. These two elements are so arranged as to act either separately or jointly, according to exigencies, upon the mechanism controlling the elevating rudder at the front of the aeroplane. The anemometer, which is shown in diagrammatical representation in Fig. 26 and in greater detail in Fig. 27, comprises a plate *P*, mounted on four rods *T*, connected with two tubes *A* which slide smoothly in an aluminum body *S*. Springs R_2 oppose the tendency of the air to force back the plate *P*, when the latter is moving in a direction from left to right. The strength of the springs is so adjusted that when the relative wind pressure is equal to or greater than that required to sustain the aeroplane, the springs R_2 are compressed to their limit and the tubes *A* thrust back against a shoulder upon the aluminum casing. If the pressure of the wind falls below this value, the springs R_1 act on the weights *M*, which in turn, through the pins *O*, thrust forward the rods *E*. These latter rods are rigidly connected with the sliding piston rod *N* of an auxiliary motor, the cylinder *C* of which receives through the chamber *D* compressed air acting upon the piston B_1. There is no need to enter into detailed description of the auxiliary motor, the principle of which is well known; air is admitted into the compartments *H* and *I*, according as the displacement of the piston rod *N* opens or closes the admission port shown in dotted lines. The surplus air escapes through

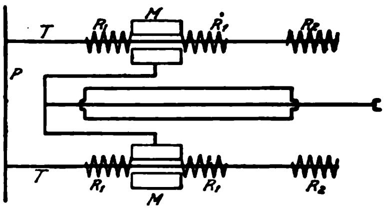

Fig. 26. Diagram of Doutre Stabiliser

openings at the end of the rod N, or the piston B_1, as the case may be. Every displacement of N is immediately followed, in consequence of the arrangement described, by a displacement in the same direction of the piston B_1. This latter actuates the rudder through a pivoted point B_2.

So far the control of the rod N by the springs R_2 has been described. But there is a second control, which is effected by the two weights M. These are ordinarily kept stationary by the springs R_1. But if the aeroplane makes a sudden plunge, the inertia of the weights causes them to lag behind the motion of the body of the machine; thus there is a relative motion of the weights M in regard to the tubes A upon which they slide, a motion which is directed either forward or backward according as the acceleration of the machine is negative or positive. These movements of the weights are transmitted to the rods E by the pins O, and thus react on N and the auxiliary motor much in the same way as the plate P. A force of 100 grams weight (3.2 ounces) is sufficient to affect the apparatus, while the auxiliary motor, which receives its air supply from the aeroplane motor, readily gives a thrust of 10 to 30 kilograms (22 to 66 pounds). This is more than sufficient to operate the rudder.

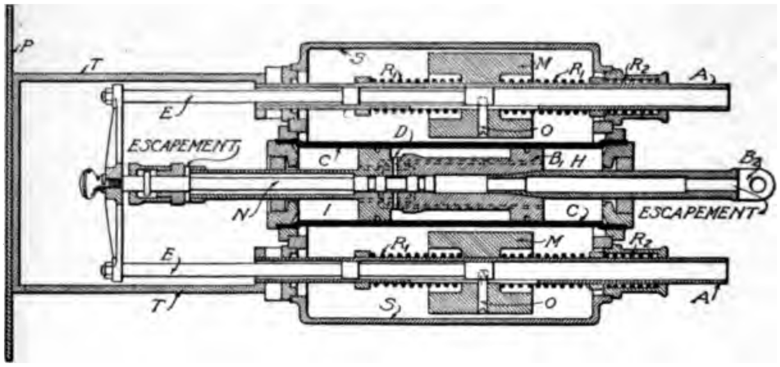

Fig. 27. Detail Section of Doutre Stabilizer

The anemometer plate and the accelerometer weights both act independently and simultaneously upon the elevating rudder. Their effect is either added or opposed, according to the conditions of flight, and the whole is adjusted so as to give the proper steering upon the rudder. Since each variation in the angle of the rudder brings about a variation in the aeroplane speed, the apparatus acts to correct the effect of its own action on the rudder, even while this is taking place. It is also to be noted that the apparatus does not wait to act until the aeroplane has taken a false movement, but it acts directly under the shock which also tends to act upon the aeroplane, thus taking account of the cause itself and not the effect. The correction given to the rudder is thus very quick. The movement of the main rod of the apparatus is transmitted to the rudder in a very simple way by the use of compressed air, the air being furnished by a small compressor driven from the aeroplane motor itself. The compressed air piston device is operated by the main rod, and the piston movement is transmitted in a suitable way to the rudder, independent of the pilot's levers. The pilot can work the rudder himself or he can remove his hands from the levers and allow the automatic device to do the steering, at least for a short time.

Trials of the Doutre stabilizer have shown it to be so sensitive in action that the pilot has removed his hands from the levers while the machine was still rolling on the ground, and the automatic apparatus has assumed control of the aeroplane causing it to rise, the operator again taking hold after reaching an elevation of 60 feet. The aeroplane was then sent up to a height of 1,000 feet, and again entrusted to the stabilizer, the pilot keeping his hands on the levers, but not working them. It was noted that the small plate kept up a slight beating movement, working back and forth over some three inches, as an indicating pointer showed; the rudder followed up this slight movement, so that the flight was very steady. The levers moved somewhat under the action of the apparatus, despite the fact that the pilot kept his hands on them. He then raised his hands for periods of four to six seconds, resuming them only to take care of the side steering to avoid a rolling movement. At times it was quite evident that no effort was required, the automatic device doing all the steering. When the pilot tried to oppose the action of the stabilizer he had to use quite a little force. At one time, the apparatus was left to itself entirely for twelve seconds; then the pilot slowed up the motor several times, and each time the plate and the moving weights gave the right action to the rudder.

Returning, the motor was slowed up and the aeroplane descended on a very good slope and the apparatus always corrected the descent so that it took place under the best conditions right to the moment of landing. The action is shown diagrammatically in Figs. 28, 29, and 30. The test was thus very conclusive, and numerous others made subsequently proved equally satisfactory. Three aeroplanes for the French army have been fitted with the Doutre apparatus.

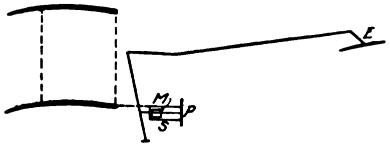

Fig. 28. Doutre Stabilizer. Action of *M* on Sudden Acceleration

Ellsworth Lateral Stabilizer. Supplementing the good results obtained with the French longitudinal stabilizer just described is an American device for maintaining lateral stability, which after all is quite as important, if not more so. As a general rule a properly-designed aeroplane is well balanced longitudinally and does not ordinarily tend to pitch, while its lateral stability is a matter that has to be corrected every few minutes during the entire flight. The device is the invention of a resident of Portland, Oregon, and is the first lateral automatic stabilizer to be successfully tried out in practice. The mechanism consists of two rotating electromagnets driven in opposite directions by a gear. An armature between these two multipolar magnets is keyed to a shaft carrying a drum so that any movement of the armature carries the drum with it. This drum carries cables connected to the ailerons or wing tips for balancing. An electric circuit is completed by an arm of a pendulum dipping into a mercury cup upon the listing of the aeroplane to either side. One of the rotating magnets is then excited and exerts a magnetic pull on the armature, thus rotating the drum. The drum shaft, however, terminates in a gear, and the block containing the mercury contact

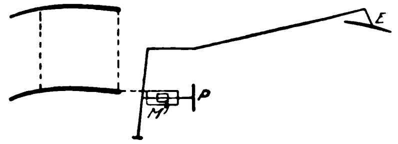

Fig. 29. Plate *P* Sets Elevating Rudder for Descent if Speed Slackens

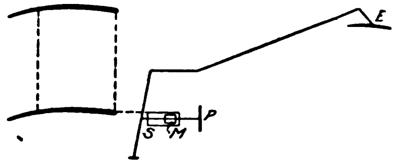

Fig. 30. Motor Breakdown Sets Rudder for Volplaning

cup is so attached to the gear wheel that the rotation of the latter will drop the cup away from the pendulum arm, again breaking the circuit and leaving the ailerons set to right the aeroplane. As the latter resumes its normal level of flight, the action of the stabilizer is reversed, returning the ailerons to their normal neutral position. Means are provided which permit the aviator to rotate the block containing the mercury cups at will, thus making contact for banking the aeroplane to any required angle to round a curve. A movement of the block does not cause any movement of the gear wheel, yet a movement of the latter causes a relative movement of the block. This permits the aviator to alter his angles laterally, of course, at will without in any way interfering with the automatic control. It can be applied to fore and aft, as well as lateral, control. One of the Ellsworth stabilizers was fitted to a Curtiss biplane during the fall of 1911, and, in the course of an extended series of flights, it was said to respond instantly to the least variation from the horizontal far more quickly than could be detected by the aviator himself. This was learned by having the wires from the ailerons connected to the steering post, which was pulled from side to side by the action of the automatic control in maintaining the balance, before the aviator was even aware that the balance had been sufficiently disturbed to make this necessary. In turning corners, the stabilizer banks the aeroplane automatically by having the mechanism connected to and controlled by the steering wheel, thereby banking the machine at just the required angle for the turn; but the amount of this banking is always at the instant command of the aviator should he desire to make it more or less, and the automatic balance is not interfered with in any way. The device is very compact, weighing but 18 pounds, and is adapted to be driven directly from the aeroplane motor, but it can also be arranged so as to be driven from an electric motor and storage batteries to provide against stoppage of the driving motor, in which case the drive would automatically be taken up by the electric motor. This addition, however, would involve extra complication and weight that ordinarily would not be considered justifiable.

While many investigators are working on the problem of automatic stability as revealed by the various devices described here, opinion as to the necessity of providing any automatic form of control is more or less divided at the present writing. It seems probable, however, that the perfected machine of the future will embody this feature, and that it will be of such a flexible character as to permit manual control of the machine at all times and yet be capable of preventing such complete loss of equilibrium as seems to have occurred in the cases of Moisant, Hoxsey, and Johnstone—in other words, a self-righting ability analogous to and approaching as closely as possible to that shown by the birds when accidentally capsized in violent winds. Hoxsey's death, for example, which is generally thought to have been due to loss of consciousness resulting from the sudden change of altitude, might have been averted by such a device as it would have brought the machine to the ground without damage.

ALTITUDE AND ITS MEASUREMENT

Nothing more strikingly reveals the great development of the aeroplane in a very short time and the absolute command over it that has been achieved, than the rapidity with which altitude records have followed one another. It will be recalled that the pioneers of aerial flight had quite as much difficulty in learning to fly as they did in designing a machine in which to accomplish it, and they trusted themselves to a motor-driven craft only after having thoroughly mastered the principles of the art through long-repeated practice in gliding. There was, therefore, nothing strange in the fact that although flight in a heavier-than-air machine was actually a reality, the flyers preferred at first to remain close to the ground. For this reason there was keen and widespread disappointment among the spectators who attended the first public exhibitions of flying in this country by Farman, the Frenchman. The manner in which he kept close to the ground, never exceeding a height of 50 feet and oftener remaining within 30, was not at all satisfactory to the crowd to whom the definition of the word *flying* did not mean the ground-skimming swoops of the sparrow, but the lofty soaring of the eagle or larger birds. From a spectacular point of view, Farman's exhibition was an utter failure.

Altitude Records. With increasing confidence, heights of 200 or 300 feet were attained and at some of the earlier French meetings the height reached by the aviator was determined by means of a captive balloon anchored over the field. If the contestant flew above it, he surpassed the former record and there was not much question of definite figures. But advancement was so rapid that this plan very soon became obsolete. From the few hundred feet that seemed to mark the limit in the early part of 1908, Morane rose to 2,500 meters or 8,202 feet but little more than a year later, September 3, 1909. This eye-opening performance showed what could be done and immediately inspired confidence in others. Competition was fostered by numerous and substantial prizes offered for altitude at meetings, and one record followed another, Johnstone reaching a height of 9,714 feet in a Wright biplane during the International Meet at Belmont Park in October, 1910, and Drexel surpassing this in a Bleriot monoplane only a few weeks later at Philadelphia by attaining an altitude of 9,897 feet. As this record stood but little more than a month before being raised by the very liberal margin of more than 1,000 feet by Hoxsey who soared to an altitude of 11,474 feet in California on December 27, 1910, it is quite apparent that a point has already been reached where the matter of soaring is one limited only by human rather than mechanical shortcomings. In other words, it seems quite possible that an aeroplane can be flown as high as human endurance will permit. The various elevations attained by human effort are shown in Fig. 31.*

It has been a matter of common knowledge for many years that ascending to great heights on mountains is attended by considerable physical discomfort and is accompanied by disagreeable physiological symptoms. Some individuals are peculiarly susceptible to the latter and claim to be affected by them at an elevation of only a few thousand feet. While mountain climbing offers some analogy to aeroplane climbing, the gradual transition from the heavier to the lighter and more rarefied atmosphere permits ample opportunity for the body to accustom itself to the change. In contrast with this, it has been common for aviators to travel the first 7,000 or 8,000 feet of their record-breaking upward flights in a little more or less than half an hour. Hoxsey is said to have risen the first 9,000 feet of his record flight in California in thirty-five minutes. This is equivalent to being transported upward a mile and three-quarters in about the

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*These were considerably surpassed in 1911, Beachey having risen well over 12,000 feet at the Chicago Meet in August, while French aviators have also been making new altitude records.—Ed.

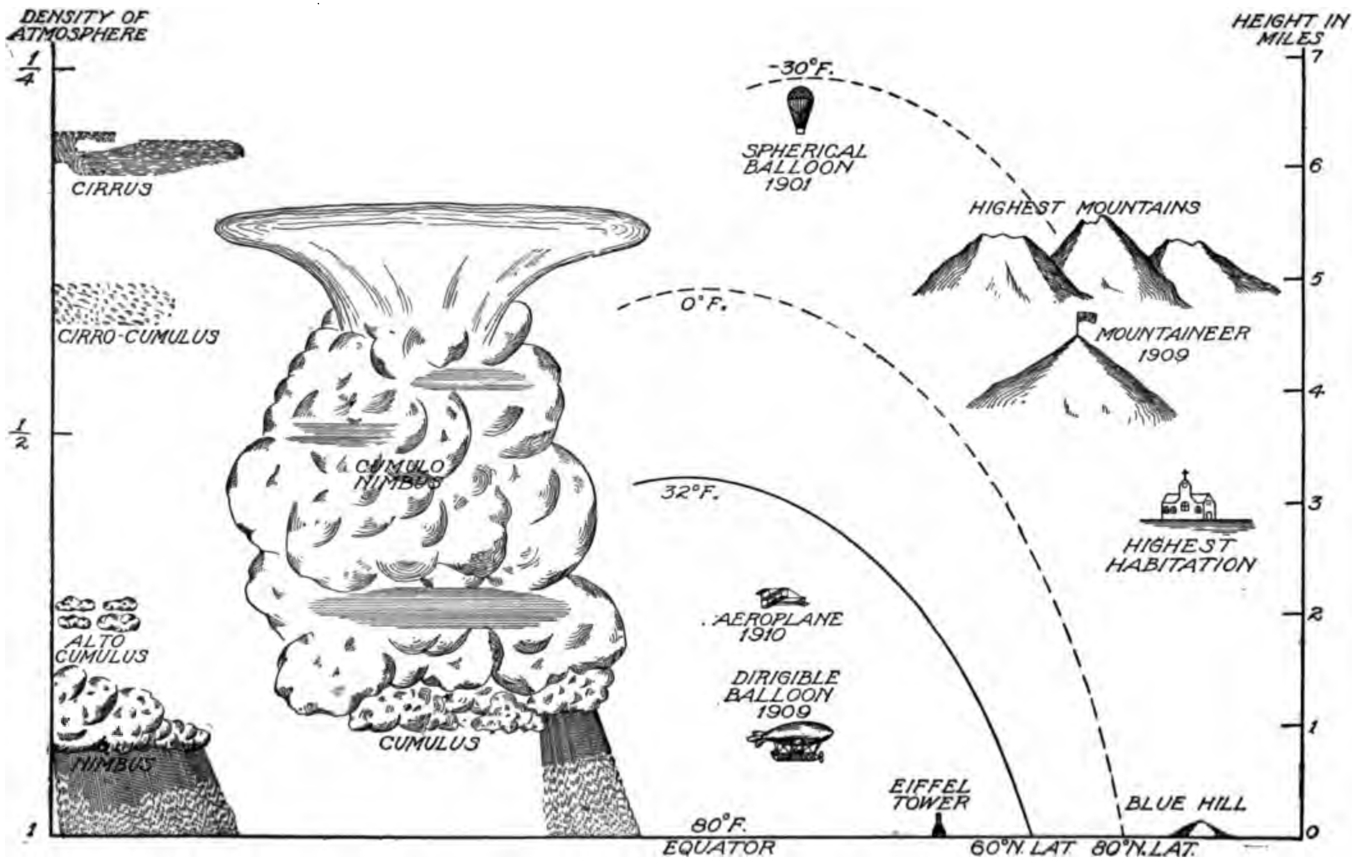


Fig. 31. Heights Attained by Man through Various Agencies

same time that it would take the express elevators of one of our sky-scraping towers to make the same distance. The barograph record of Hoxsey's flight at Belmont, Park October 27, 1910, Fig. 32, shows that he rose to a height of over 5,000 feet in the first thirty minutes. In this flight, however, he found the wind too severe and reached an elevation of only 6,500 feet; in attempting to get down, he dropped the whole distance in less than fifteen minutes, having been blown backward about 30 miles. Fig. 33 shows the record made at the same time and place by Johnstone when, although facing the wind, he was blown backward 42 miles. It is well known that the sudden transition from the high pressure of a subaqueous tunnel or foundation caisson to the normal sea-level atmosphere is often attended with fatal results, and it does not seem unlikely that the reverse process of going from a comparatively low pressure to a much higher one in a short time, as where the aviator descends from a height of 9,000 to 10,000 feet in less than 10 minutes, physical inconvenience might follow. Experiments carried out by prominent physicians in France show that such an experience is attended by a considerable increase in the blood pressure of the individual. The time of transition is so short that the circulatory system does not have time to adapt itself to the change in pressure.

The aviator, after a quick descent from anything above a few thousand feet, suffers from headache, ringing in the ears, and a high pulse, and his feet and hands are apt to be blue and numb—quite as much from impeded circulation as from the cold experienced at a great height. These experiments invariably showed that the blood pressure was increased as much as 30 to 40 per cent, despite the fact that the aviators in every case were trained athletes in full form. The rise in temperature was less apparent where the individual was fatigued, and was not present where the flight did not exceed a height of 300 or 400 feet. By the result of these experiments, the importance of descending slowly is pointed out, as well as the dangerous fatigue to which flight at high altitudes exposes the circulatory apparatus by provoking increased and irregular activity of the heart. That some of the fatalities ascribed to mechanical defects might in reality have been due to fatigue of the human machine, seems quite possible.

Methods of Altitude Measurement. *Captive Balloon.* Interest in high flying and altitude records is so general that a description of

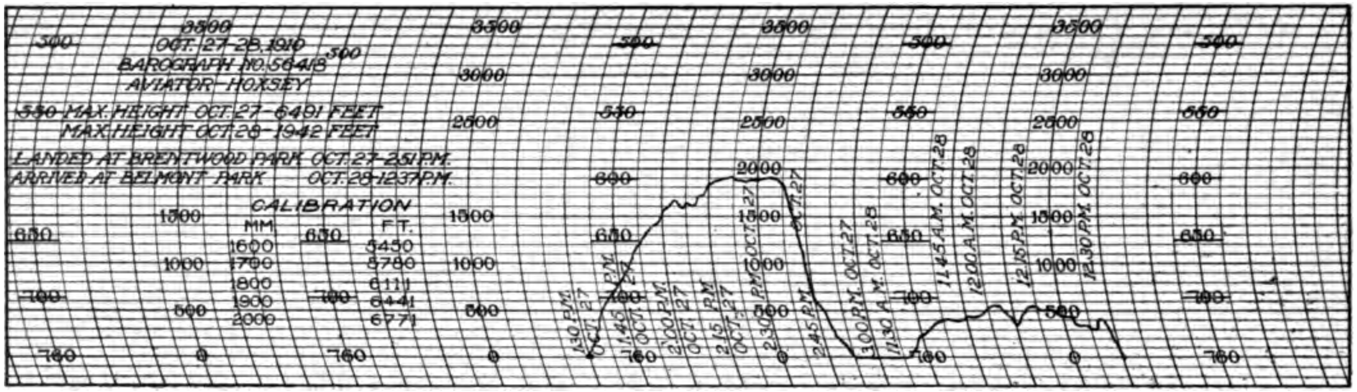


Fig. 32. Barograph Record of Hoxsey's Flight at Belmont Park, October, 1910

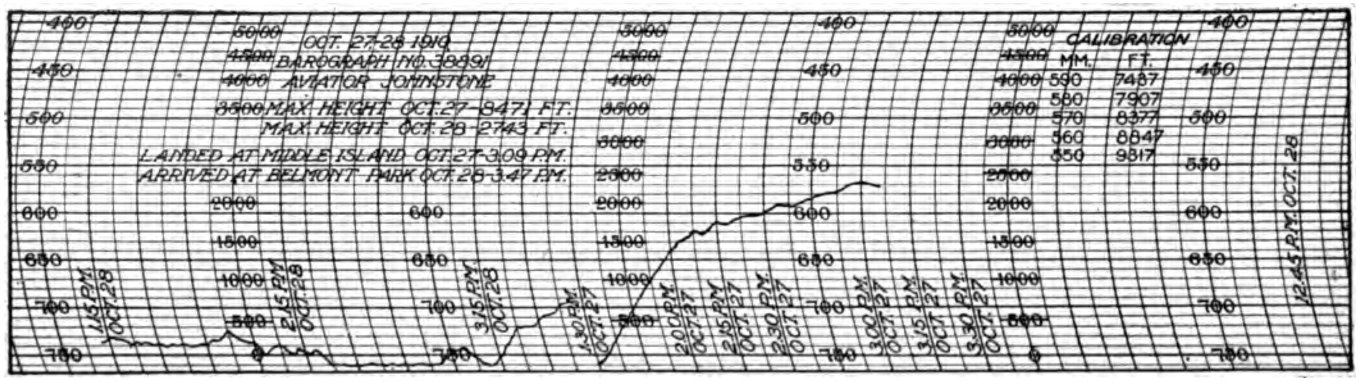


Fig. 33. Barograph Record of Johnstone's Flight at Belmont Park, October, 1910

the methods employed in ascertaining the height reached by an aviator will be appropriate here. There are numerous ways of measuring elevation—of varying degrees of accuracy—and in general the simplest and easiest are the least accurate. When a record is to be made, possibly exceeding a rival's by a few feet only, exactness is evidently a desideratum. In view of the conditions, however, it is naturally out of the question to reduce matters to such a fine point as this. A rule has accordingly been adopted recently by the Aero Club that henceforth an altitude flight is to be considered as making a record only when it exceeds by at least 300 feet the mark previously set. In 1908, getting up as much as 300 feet was in itself considered a record. At that time a certain amount of rope with a captive balloon attached to its upper end sufficed as a measure of the height reached. The fact that a calm might permit the balloon to rise straight up and stay there or a wind might carry it along some distance thus reducing its vertical height above the ground considerably made little difference. As a matter of fact, a breeze sufficient to do this was more than enough to prevent a flight of any kind.

Triangulation. The balloon very shortly becoming of no further use as an altitude indicator, triangulation was resorted to, this method being employed at the Harvard Meet near Boston, in September, 1910. By this means, two observers at the end of a measured base line watch the soaring machine and obtain its angle of elevation simultaneously. From these two angles and the length of the base the other two sides of the triangle, and, consequently, the height of its apex, may readily be calculated with the aid of trigonometric formulas. The longer the base line adopted and the more accurate the instruments employed for the observation, the more exact the result will be. The preparations for checking the heights reached by the aviators at the Harvard Meet were the most elaborate ever undertaken in this country.

It was assumed that a height of 10,000 feet might be reached, which required that the points of the base line be located something over 2 miles distant from the aviation field, in order to obtain angles which could be conveniently observed with an ordinary surveyor's transit. The time of the observations—late afternoon—necessitated a position south of the field in order that the observers might have the sun behind them, and made possible the utilization of high ground for the observation stations. The work was carried on under the supervision of Prof. R. W. Wilson, of Harvard University, Albert J. Holmes, an engineer of Cambridge, being stationed at the other observation point. Station *A* was located on the slope of Forbes Hill, Quincy, and Station *B* was at East Milton in an open field. Either station could be seen from the other, but as a direct measurement could not conveniently be made between them, the distance was figured from indirect measurements and was found to be 6,236 feet. The distance from the aviation field was about 2¾ miles, so that had any one of the aviators reached an altitude of 10,000 feet, his angle of elevation would not have exceeded 35 degrees.

Back of each station, in the line of the base, range poles covered with alternate strips of black and white cotton cloth and surmounted by a signal flag were erected. Around the hub marking each station, three stakes, on which to place the instrument, were driven flush with the ground, thus insuring a quick and stable set-up. Sun and wind shelters for the instruments were also provided, and telephone connections were made between the two stations and with Professor Wilson's office on the aviation field.

The recorder at each station was also the telephone operator, who was provided with a head and breast attachment for receiver and transmitter. When notice was received from the field that an altitude flight was about to be attempted, both stations were called and the standard chronometer time given. The operators' watches were compared with this standard and the result recorded. At the same time, the name of the aviator and the type of machine to be used were given. As soon as the aeroplane could be seen from both stations, the recorder at Station *A* would give the word to get ready, at which both the observers trained their instruments on the aviator himself, Fig. 34, as representing the center of gravity of the machine. An answer of "all right"was then passed back to Station *A*.

Each observer then followed the movements of the aeroplane by turning the upper motion of the transit with his left hand—the lower motion having been set at zero on the base line—and moving the telescope up or down with his right hand by means of the tangent screw on the vertical circle. The signal "all right" was repeated back and forth until the recorder at Station *A* would say "set," at which the observers would cease moving their instruments and read to the recorder the resulting horizontal and vertical angles. At the same signal each recorder noted the time to the nearest second. The recorded time reduced to standard time served to identify corresponding observations. Eight series of observations were taken on five different days during the course of the meet. While there was nothing new in the methods thus employed in determining altitude, the conditions were such as to call for smoothly-working instruments in perfect adjustment, and the observers and recorders had necessarily to be on the alert. Approximate heights obtained by sextant observation were announced on the field after each flight. Aneroid barometers and other apparatus were also used on the machines themselves, but the official altitudes were computed from the obser-

Fig. 34. Triangulation Method of Measuring Altitudes

vations described above and were made public only after having been carefully worked out at the close of the day's events. The best height reached during the course of this meet did not approach the existing record at that time. It was a flight of 3,860 feet made by Brookins in a Wright biplane. The same aviator had previously ascended over 5,000 feet at Atlantic City, his altitude being determined by the same method of triangulation here described.

The cumbersomeness of the elaborate preparations involved as well as the number of trained observers and the apparatus required for carrying out this method call for scarcely any comment. Even were it a method that could be universally applicable, or, in other words, adapted to any conditions, it could hardly come into general use, although the fact is conceded that it is the most accurate method. It will be evident that as it depends entirely for its working upon the ability of the observers to follow the aeroplane, regardless of the height it attains, the habit of rising "clear out of sight" that has been indulged in by the aviators in recent record-breaking flights would put the entire system out of commission. This would likewise be the case where there were any low clouds or mist to obscure the view.

A method of triangulation can also be employed from the aeroplane itself, but has the disadvantage of requiring an observer for this purpose, while observations would be difficult at the high rate of speed ordinarily attained by the heavier-than-air machine. The method is more applicable for use in a balloon or dirigible. It consists of observing two points of the imaginary base line of a triangle on the ground with the aid of an instrument having a graduated scale. The length of this base line, or distance between the two points on the ground selected by the observer, is evidently in inverse proportion to the distance from the observer's location in the balloon to one of the points. The observer sights an object of known dimensions, such as a house or a tree, thus measuring the apparent angle under which it is seen.

Acoustic Method. There is also the acoustic method by which rough approximations can be obtained of moderate heights. It consists in measuring the time necessary for sound to traverse the distance which separates the aviator from the ground and is likewise only applicable to the balloon or dirigible, also involving a special observer to carry it out. Any distinct noise made by the aeronauts will be deflected or echoed by the surface of the earth and returned to them after a certain lapse of time, measured by their distance in the air. By accurately noting the time required for a sharp blast on a horn to reach the earth and return as an echo, and multiplying this by the speed at which sound travels, the result obtained will be twice the distance above ground. However, since the speed of sound is 340 meters per second, it would be easy to make such serious mistakes in the observations as to render the latter entirely worthless for any practical purpose, a difference of only one-fifth of a second making a variation of more than 100 feet in height. Even though obtained by accurate observations, the result also requires changes and corrections according to the density of the atmosphere, and it may be altogether erroneous if there happen to exist ascending or descending currents of air at that point at the time the observations are made.

It will be easy to appreciate, for instance, how difficult it would have been to ascertain the heights attained in any of the attempts at altitude records that marked the close of 1910. The rivalry to be the first to attain 10,000 feet was very keen. Drexel came very close to this mark, his corrected readings showing a shortage of only a little over 100 feet. The record was finally made by Legagneux, who, soaring over Pau, France, reached a height of 10,499 feet. Then Hoxsey, in a Wright biplane, ascended almost 1,000 feet higher at Los Angeles on December 27, 1910. This represents a distance of nearly 2 miles from the earth and long before that height is reached such a small object as an aeroplane becomes invisible to the naked eye, and while it would be extremely difficult for one observer with a telescope to keep the tiny speck in view, it would be much more difficult for two to follow it constantly.

In the case of Hoxsey's record-breaking flight, his machine was completely lost to view for more than an hour, and although subsequent events showed that he had gone practically straight up over the aviation field—coming down again at the same place—it was impossible for numerous experienced observers to sight him even with the aid of strong field glasses. In fact, as the ascent was made in little short of a gale—the wind blowing forty miles an hour—it was feared that he had been blown away and surrounding towns were notified to be on the lookout for the machine. Only a few years ago, there was scarcely an aviator who dared rise in the air when there was more than a zephyr stirring, so that Hoxsey's ascent was an extraordinary feat in more than one sense, affording a striking illustration of the stability of the biplane. The same wind but a short time before had brought Latham's huge Antoinette monoplane to grief. (It was Latham who set the initial high mark for 1910 at 3,445 feet, in France.) On landing, Hoxsey was so benumbed that he could scarcely speak and had to be lifted from his seat and supported until his circulation again approached the normal.

Fig. 35. Barograph Mounted so as to Prevent Vibration

Barograph. The aeroplane accordingly outgrew the triangulation method of ascertaining the height reached after it had been given a few trials. Although its accuracy is indisputable, this being the means employed by civil engineers to determine the height of mountains, it was not depended upon solely even on the occasions in question, a barograph being placed on the machine in addition. Now that invisible heights have been attained, even under the clearest weather conditions, the barograph is the only resource.

TABLE I

Fall of Barometer at Different Elevations above Sea Level

(Latitude 40 degrees)

Height above Sea Level Feet	Fall of Barometer Inches
917	1
1,860	2
2,830	3
3,830	4
4,861	5

The barograph, as its name indicates, consists of a recording aneroid barometer which for aeroplane use is housed in a light but strong glass case, as shown by Fig. 35. The aneroid barometer proper is a very delicately made and adjusted vacuum box, or rather a series of exhausted cells of very thin metal, placed one above the other. It is so delicately adjusted that it is susceptible to very slight changes in atmospheric pressure, contracting as the pressure increases and expanding as the pressure decreases, as in ascending. Its movements are transmitted through a series of multiplying levers to a pivoted lever carrying at its end a small pen and a supply of ink. This pen bears against a chart wound upon a hollow drum, the latter being revolved by clockwork. The chart is graduated according to the metric system, usually representing meters of ascent, the divisions being of one millimeter each; or in hundredths of an inch, representing feet of ascent. The abscissas of the chart mark the ascent or descent and the ordinates mark divisions of time.

A mercury barometer falls approximately 1 inch for every 900 feet of ascent, as can be seen from Table I compiled at mean atmospheric pressure in latitude 40 degrees.

But despite its sensitiveness and delicacy of adjustment, the use of the barograph is not without its drawbacks. It is affected adversely by the vibration of the motor and to guard against this various expedients are resorted to. In one of his attempts, Latham suspended the instrument around his neck—a plan that rendered it necessary to take his hands from the control in order to consult it, and one that might prove annoying in other ways.. Ordinarily, it is suspended by three spring straps from guy wires or other convenient points on the machine where it will be in plain sight of the aeronaut, Fig. 35. As far back as twenty years ago Colonel Renard adopted the scheme of suspending the barometer itself inside its box or housing by means of rubber bands fastened to the different corners, thus isolating the instrument somewhat after the manner of a spider hanging in the middle of its web. The barometer thus protected was employed in connection with sounding balloons and it was found that a fall of 12 to 15 feet had no effect on it.

A further disadvantage of the barometer is what may be termed its *lag*, or *retardation*. In other words, it does not respond instantly to the change of pressure. This lag will be more or less accentuated according to the rapidity with which the altitude is attained and the pressure correspondingly modified, so that in order to obtain a correct reading at any given height a brief period must be allowed to permit the instrument to accommodate itself to the changed atmospheric conditions. The rapidity with which it will do this depends in large measure on the extent of the difference between the actual and recorded pressure at the moment. Where the variation is great the force tending to overcome the inertia of the instrument is correspondingly increased, and the atmospheric pressure may be said to accumulate a *head*, analogous to a column of water, this being true of thermal as well as barometric variation in its influence upon the recording instrument. But even with this allowance for accommodation to changed conditions, the barograph indications only approach the actual height in a varying degree, experience having demonstrated that this is almost always more or less inferior to the real altitude attained.

Since the reading of the instrument denotes only the difference in pressure between the point of departure and the altitude attained, the barograph employed must be calibrated just before being used, and its record is also subject to correction, depending upon the atmospheric conditions prevailing at the time. In fact, a resumé of the precautions observed on the occasion of Drexel's flight at Philadelphia would make it appear that this apparently very simple method is almost as elaborate as that required to obtain a similar result by triangulation. The instrument employed was a Richard, of French make, but similar in construction to the barograph manufactured by Queen and Company, Philadelphia, and illustrated here.

Being compensated for temperature, the barograph requires no correction for the effect of temperature on the instrument itself, but its reading requires correction for the effect of temperature on the atmosphere, which need be taken into consideration only when the latter is above or below 50°F. That this may be the case frequently, in fact practically always, is illustrated by the sufferings of aviators at high altitudes. In the monoplane with the motor at the head, the aviator sits directly in the blast of the propeller and it appears to be next to impossible to wear sufficient clothing to prevent suffering from the cold. Drexel, Fig. 36, wore several sweaters in addition to a specially fleece-lined skin suit. The daily press reports of Hoxsey's flight at Los Angeles mentioned that the aviator was afraid that "the carbureter of his motor would freeze," in other words, choke up with ice and stop the motor. This might have been the case with a motor of the ordinary type, but the Wright motor could hardly suffer from such a defect as it is not equipped with a

Fig. 36. Drexel Preparing for an Altitude Flight

carbureter of any kind. Instead, it is fitted with a small gasoline pump which forces the fuel directly to the inlet valve of each cylinder. As an automatic inlet valve is employed, the spring tension of the valves might prove excessive under the diminished pressure encountered at high altitudes, thus greatly cutting down the supply of air through the decrease in the maximum opening of the valve, but this does not appear to have occasioned any trouble thus far. The Antoinette motor is also fitted with a gasoline pump to feed the fuel, instead of the usual carbureter. In the case of the latter, the lowering of the temperature is aggravated by the rapid evaporation at the air intake, a tendency that has brought about a very general use of the water-jacketed type of carbureter on the automobile.

In reading the barograph, it is customary to apply, for correction of temperature, the carefully worked out tables of Sir G. Airy, late British royal astronomer. Carrying the instrument about is apt to derange it through the jolting it receives, so that in order to insure accuracy, it is necessary to calibrate it before a flight. Before Drexel's attempt at record breaking, his Richard barograph was carefully tested by the experts of Queen and Company, with the assistance of the expert of the weather bureau. This was done by placing the instrument in the receiver of a large air pump and exhausting the air. Connected with the partial vacuum in which the instrument rested was a column of mercury, which had previously been accurately adjusted for temperature, altitude, and capillarity. In the course of exhausting the air, the instrument passed through all the changes represented by an ascent from sea level, or an atmospheric pressure of 29.92, to an elevation of 15,000 feet, and was found to register in absolute coincidence with the mercurial column. The inclosing cover having a glass front and permitting the instrument to be seen, but not touched, was then sealed, and attached to the Bleriot monoplane. Immediately after the conclusion of the flight, the instrument was again taken to the laboratory and subjected to a similar test, which proved it to be in good order and correct in its indications. The following are the results of the examination:

The difference in atmospheric pressure between the upper and lower stations on the barograph record was 9.302 inches. At the time of the ascension the pressure at the ground, as indicated by the record, was 30.05 inches and at the altitude attained was 20.75

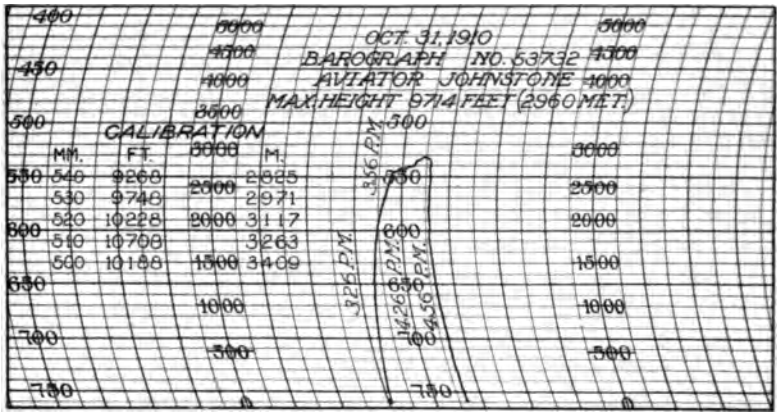
inches, giving a difference of 9,929 feet on the basis of pressure at sea level of 29.90 inches at a temperature of the air of 50°F. Making a correction to the pressure of the lower station (plus 136 feet), correction to the mean temperature of the air column (minus 205 feet), correction for the gravity at Philadelphia which is in latitude 40 degrees North (plus 5 feet), correction for moisture in the air column (plus 32 feet), we have 9,929 plus 136 plus 32 plus 5 minus 205 feet= 9,897 feet, as representing the actual altitude reached.

The temperature of the upper air is also of some importance in determining the final result, and while no recording thermometer was carried by Drexel, it just so happened that the United States Weather Bureau had its temperature kites flying from Mt. Weather at an altitude of 13,000 feet, the air currents at the time flowing from the southwest directly over Philadelphia. It was thus possible to apply an accurate correction for the temperature of the upper air stratum, there being at that altitude no local conditions to affect the result.

From the foregoing, it will be apparent that the making of an altitude record with the barograph is almost as delicate and involved a matter as determining the height by triangulation. For the comparison of records and to establish indisputably the rights of each competitor, it is essential that the results be determined with the utmost exactitude attainable. Thus Drexel's flight, while an extremely creditable performance, particularly in view of the time of year it was made, did not constitute a breaking of the record made by Johnstone in the special Wright biplane at Belmont Park a month earlier, as his increase did not exceed the new limit of 100 meters, or 328 feet, the actual difference being only 183 feet. On the other hand, the public is anxious to know results on the spot, and to satisfy the clamor the actual reading of the barograph is usually given, it being understood that such figures are subject to modification by careful verification, as precision is incompatible with rapidity.

In addition to the numerous corrections that have to be made before the record can be considered properly verified, there is also the danger of deranging the instrument through the jolts it may receive in the starting and alighting of the aeroplane. The barograph must be calibrated just previous to the ascent and verified as soon afterward as possible, the former being particularly necessary as the instrument may have been carried a long distance in an automobile or railway train, as was the case with Drexel's instrument.

Individual Barograph Records. *Johnstone.* A comparison of the experiences of aviators who have reached great heights is of interest in this connection. In making his record-breaking flight at Belmont Park, the barograph record of which is shown in Fig. 37, Johnstone was only 35 minutes in reaching the 8,000-foot level, but it took him almost an hour to ascend the remaining 1,000 feet of his flight. He descended at a terrific rate in one long dive that required only 5 or 6 minutes to bring him back to the ground—a somewhat foolhardy proceeding that might have had serious physical results, as already explained at the opening of the present subject. Johnstone kept his motor throttled coming down and accordingly did not have the terrifying experience that Brookins passed through earlier in the same meet when he was forced to descend from a height of 5,000 feet in the Wright "baby" biplane with a dead motor. The machine was considerably damaged in alighting but Brookins was unhurt.



MM.	FT.	M.
540	9268	2825
530	9748	2971
520	10228	3117
510	10708	3263
500	10188	3409

Fig. 37. Barograph Record of Johnstone, Showing Rapid Ascent

Johnstone was fond of "hair-raising stunts" such as these steep dives and lost his life shortly after as the result of a similar performance at Denver in the middle of November. On the occasion of his lofty flight at Belmont Park in October, Johnstone did not experience any discomfort from his exceedingly rapid transition from a height of almost 2 miles with its rarefied air down to the normal atmospheric pressure to which we are accustomed at sea level.

Drexel. It was otherwise with Drexel at Philadelphia. During his first attempt to break Johnstone's record, he was attacked by mountain sickness—one of the numerous fanciful appellations under which nausea travels—and, in addition, he was numb with the cold. At the time, he was at an elevation of 8,373 feet which he had attained in about 45 minutes and, as he was then over the Atlantic Ocean, he immediately started downward in long spiral sweeps, Fig. 38. The second attempt was made a few days later and it accentuated the experience which most aeronauts have encountered in rising to a great height—that is, the ease with which a certain altitude between 8,000 and 9,000 feet is attained and the difficulty met in getting any higher—as illustrated by the fact that Johnstone made his ascent of the first 8,000 feet in little over half an hour, but was almost an hour in rising 1,000 feet more.

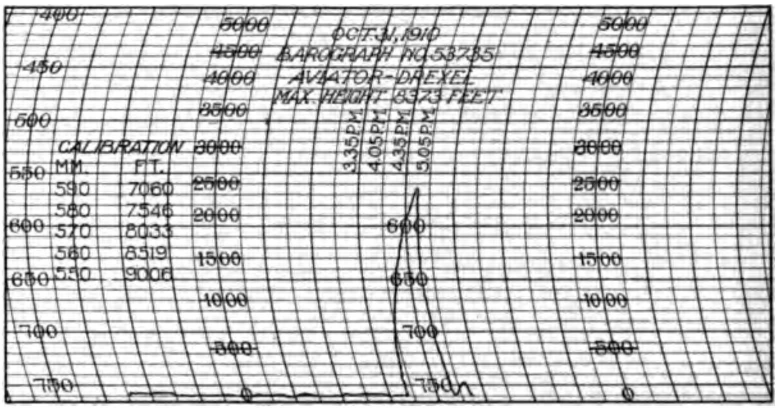


Fig. 38. Barograph Record of Drexel, Showing Rapid Ascent and Descent

When Drexel's barograph recorded within less than a hundred feet of the then coveted 10,000-foot mark, it seemed impossible to go up any higher. It will be recalled that the actual reading of the instrument lacked only 71 feet of this figure, but numerous attempts to ascend farther in spirals, as is usually done, made no impression

TABLE II

Aeroplane Altitude Records for 1910

Date	Name	Machine	Place	Altitude
Jan. 7	Latham	Antoinette monoplane	France	3,280
Jan. 12	Paulhan	Farman biplane	United States	4,165
July 9	Brookins	Wright biplane	United States	6,171
Aug. 11	Drexel	Bleriot monoplane	England	6,600
Sept. 3	Morane	Bleriot monoplane	France	8,471
Sept. 8	Chavez	Bleriot monoplane	France	8,485
Oct. 3	Wynmalen	Farman biplane	France	9,104
Oct. 31	Johnstone	Wright biplane	United States	9,714
Nov. 23	Drexel	Bleriot monoplane	United States	9,897
Dec. 9	Legagneux	Bleriot monoplane	France	10,499
Dec. 27	Hoxsey	Wright biplane	United States	11,474

whatever on it. The expedient of making a sudden dive and then shooting upward with the momentum thus gained, roller-coaster fashion, was then tried but failed to result in forcing the machine more than a few feet higher. The descent was made in a perfectly straight line at an angle which brought the machine to the ground at a point 12 to 15 miles distant from the starting field.

Legagneux. Although Drexel did not succeed in breaking Johnstone's record officially, the latter only remained valid for a very short time, Legagneux reaching a height of 3,200 meters, or 10,499 feet, within less than a fortnight later, December 9, 1910. This was accomplished in a Bleriot monoplane although this French aviator had previously been closely identified with the Farman biplane. In one of the latter machines he successfully made *Le Circuit de L'Est*, one of the leading French long-distance flights, constituting practically an aerial circumnavigation of France—a trip of several hundred miles. He also made the 180-mile flight from Paris to Brussels with a passenger in a Farman, covering the distance in slightly less than 3¼ hours or an average for the distance of near 60 miles an hour, which is remarkable in view of the load carried.

Summary of Altitude Records. How rapidly altitude records followed one another during the year 1910 will be evidenced from a glance at Table II.

As the new rule making necessary a difference of 100 meters to constitute an official record went into effect only a short time before

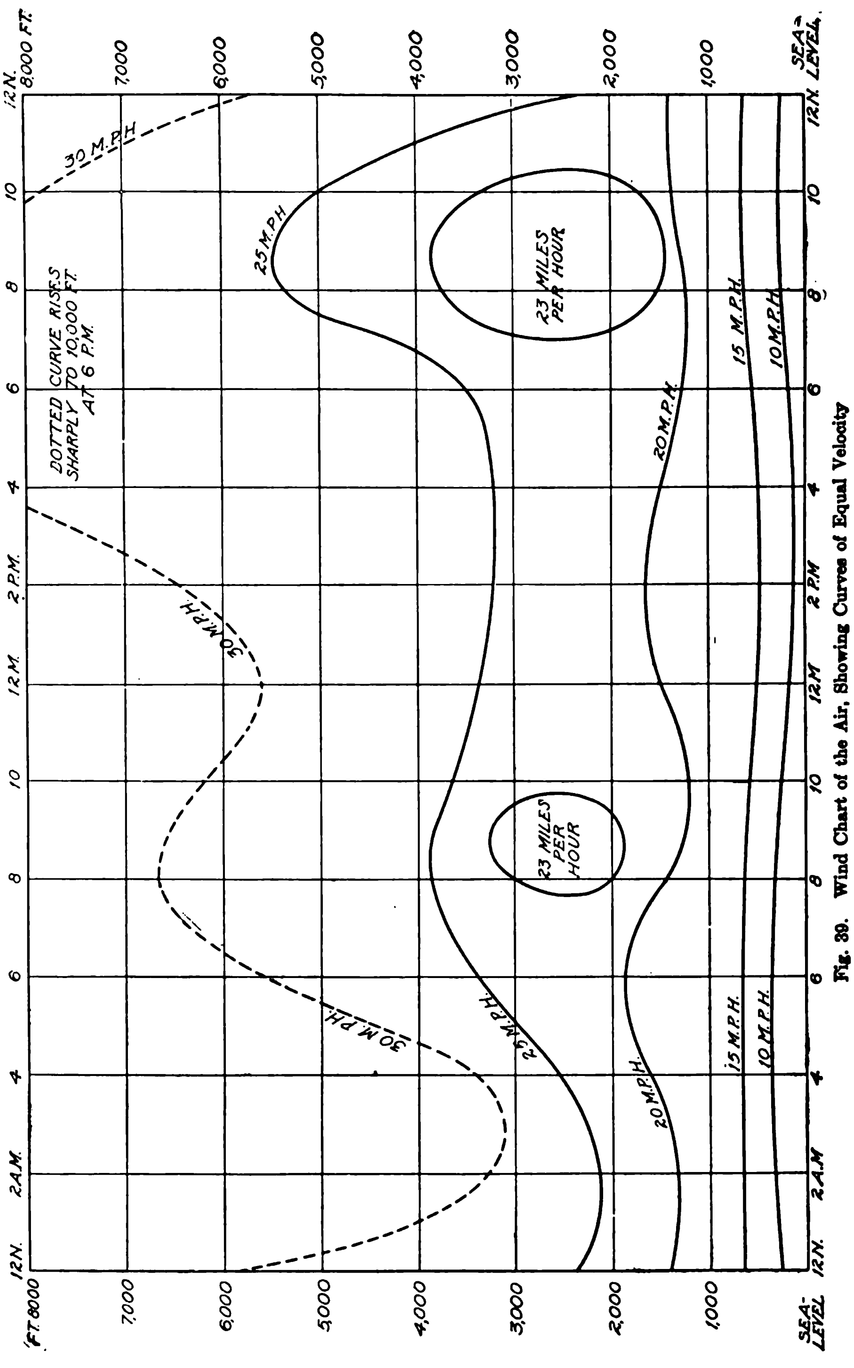


Fig. 39. Wind Chart of the Air, Showing Curves of Equal Velocity

Drexel's flight at Philadelphia, those preceding his accomplishment were officially regarded as setting up new altitude marks regardless of the slight difference that may have actually existed between the new height attained as compared with the one just given. This is noticeable in the flights of Morane and Chavez—the latter of whom made his record in crossing the Italian Alps—there being a margin of only 14 feet. This, taken in connection with the numerous corrections necessary in the reading of the barograph before the actual height attained can be accurately calculated, makes apparent the wisdom of the rule in question.

That the instruments will give remarkably uniform results when carefully checked, however, may be noted from the experience of the International Aviation Meet at Belmont Park, in October, 1910—one of the most important events of the year. At times, there were as many as eight or ten machines of different types in the air at once. All of the altitude instruments used were carefully calibrated in advance by Major Samuel Reber, U. S. A., who served as a member of the Contest Committee of the Aero Club of America. The formula of Laplace was used in this work and, as the corrections for temperature were allowed, the results as shown by the barograph records were practically correct. Each instrument was calibrated separately, the readings being checked at every 50 millimeters on the chart. So accurate were the results thus obtained, that two barographs sent aloft on the same aeroplane varied from each other by only 13 feet, or less than the width of one of the recording lines which were equivalent to a height of 17 feet.

In view of what has been accomplished in less than a dozen attempts spread over the course of a year, it would be futile to attempt to predict what the next few years may bring forth in altitude records. With a water-jacketed carbureter to prevent freezing at the low temperatures encountered at great heights even in midsummer and a means for compensating for the increasing rarity of the air in order to prevent the efficiency of the motor from falling off too rapidly, as the supply of oxygen decreases in proportion to the volume of air, there would appear to be only one limit to the heights attainable—that of human endurance. Adapting the motor to the extreme range of conditions under which it must operate in traveling from sea level to an altitude of 2 to 3 miles or more without serious loss of efficiency, is an apparently simple matter. In addition to the precautions against freezing, means have to be provided for mixing a very much greater volume of the rarefied air with the gasoline in order to maintain the supply of oxygen at a point where it will be sufficient to create an explosive mixture of equal power to that normally obtainable at much lower levels. Otherwise, there would appear to be no difficulty in running the motor with practically the same power output, regardless of the height attained. Adding to these precautions the fact that at certain points the characteristic hourly wind velocities for different altitudes have been obtained, as shown in Fig. 39—a sort of chart of the air which will warn the aviator of the dangers he is liable to encounter—it seems as if all of the difficulties except those inherent in the aviator himself had been guarded against.

The ability of the human organism to withstand the sudden transition from normal atmospheric pressures to a very low pressure, and *vice versa*, without serious physiological results, is a different matter. There are undoubtedly individuals who are but slightly susceptible to this or, at any rate, very much less so than others, as witnessed by Johnstone's experience, and with inducements in the form of cash prizes, these aviators are likely to come forward. At present the heights attained represent only about a third of the distance reached in ordinary spherical balloons and slightly more than this proportion of the altitudes reached in mountain climbing, Fig. 31. It is true that bleeding at the nose and ears, and even loss of consciousness, has resulted from reaching extreme altitudes in a comparatively short time, as where a balloon has suddenly shot up to a great height. Being overcome in this manner would naturally end fatally in the case of the aeronaut who has to be alert every moment in order to insure his safety. He has no sheltering basket in which he can safely remain inert until the recurrence of normal conditions revives him. Despite these dangers, it seems quite probable that the course of the next few years will mark the attainment of great heights in a heavier-than-air machine—in fact, altitudes marking the limit beyond which human life can not be sustained. It is no longer a question of mechanics nor of confidence in the ability of the machine to accomplish what is demanded of it, but merely one of human endurance.

Although the air has the apparent advantage of being a highway without hills, it is evident that there is more need for climbing than on solid ground, and this need will increase with the number of aviators until it will become necessary to go up or down to avoid machines approaching from other directions. Climbing, in fact, is one of the first feats to be mastered for at the very start the aeroplane must be driven upward to clear obstructions. If the angle of ascent be too great, the machine may very quickly lose headway and come to a standstill, under which circumstances a sudden slant in almost any direction might result with an inexperienced driver and would probably be followed by a fall. The latter would be caused by the almost total loss of the effective supporting surface through such a radical alteration of the angle of incidence.

This, and the experiences of Johnstone, Drexel, Hoxsey, and others who have ascended to great heights, suggest the importance of employing a gradometer on the machine. When these aviators went out of sight of the ground, and particularly when enveloped in a cloud, they found it difficult to determine whether the machine was heading up or down, except when the angle was acute enough to be readily perceptible. The gradometer as used on automobiles is nothing but a small spirit level with a scale calibrated to indicate the angularity of ascent or descent in degrees. Every machine has its peculiarities and there is an angle at which it climbs most effectively, while in the case of fog close to the ground it would be of great assistance to the aviator by indicating whether the aeroplane was approaching the ground or the reverse.

AERONAUTICAL PRACTICE

PART II

LEGAL STATUS OF THE ART

Wright Patents in American and Foreign Courts. Probably no single phase of aviation is as little known by those who should be well informed on the subject as the actual status of aviation where the Wright patent is concerned. The move on the part of the Wright Brothers to establish the standing of their patents by having them adjudicated and, as this is an extremely lengthy process, to restrain infringers in the meantime, has led to a perfect flood of criticism—even abuse and vilification—all of which has been misguided, to say the least.

A clear understanding of the situation as it now stands may be obtained from the following brief resumé of the events that led up to this attitude. nI December, 1903, the Wright Brothers first succeeded in flying a motor-driven heavier-than-air machine guided by man. The adoption of the wing-warping device used in connection with the operation of the vertical or direction rudder of the machine, which made this possible, marked the culmination of centuries of effort bent upon the same goal, and which in the twenty years just preceding had engaged the talents of many of the world's noted scientists. It must be conceded by even their most bitter antagonists that they were the first to actually fly; moreover, that although others may have suggested or even attempted to use a device similar to theirs, they were the first to perfect it, and that the state to which they developed it made the general introduction of flying possible. To refuse to admit this is merely going contrary to the facts. It must be further conceded that they were the first to obtain patents on a device of this nature which had actually proved operative. The importance of this will be pointed out later.

There is accordingly presented on the one hand a patentee who, after years of labor and the expenditure of a considerable sum of money, has succeeded in inventing a device of an absolutely revolutionary nature; on the other hand, an enormous number of investigators in the same field who wish to avail themselves of his hard-earned success without in any way contributing to the reward which should be his. The United States courts held that Alexander Graham Bell was the first to perfect a device for the transmission of speech over a wire. A situation analogous to that now presented in the field of aviation would have arisen, had the public claimed the right to help itself to Bell's telephone thirty years ago. But a telephone could not be manufactured, bought, or sold, for love or money, except by the Bell Telephone Company, up to March, 1893—the date the patent expired. The restriction of a utility of such far-reaching importance could be criticized as an unjust monopoly, and undoubtedly the lack of competition retarded the development of the art, as was shown by the strides it made when the bars were let down, but there was no possible legal basis for complaint.

There appears to be little doubt but that the Wright patent is quite as basic as that of the telephone. Speaking over a wire was generally considered quite as much of an impossibility before Bell's invention, as flying was before that of the Wright invention. Whether the Wright Brothers decide to grant licenses to manufacture on a royalty basis, once their patent has been successfully adjudicated, is entirely for them to decide. Their non-committal attitude on the question in the meantime, despite the precedent of the Selden automobile patent under which numerous licenses to manufacture were granted pending its ligitation, has led to a great deal of criticism with "hampering the development of the art" as its chief foundation. But there is quite another side to the question. It has been shown to be possible to fly without utilizing the Wright device, as in the original Voisin biplane, but not with any great degree of speed or safety; or again, as in the case of the Pfitzner monoplane, the possibilities of which have not been fully put to the test as yet. The necessity of competing against the patented device should be instrumental in advancing the art, instead of hampering its development. It is scarcely necessary to add, that these inventors, unless of a sufficiently philanthropic turn of mind to dedicate their inventions to the public, would likewise expect to reap the reward of their efforts. It is simply a case of the survival of the fittest, and should the Wright Brothers' invention prove to be the only successful method of flight, as it has proved thus far—when it is considered that all successful machines to date either warp the planes or employ a method which is claimed to infringe this—there appears to be no reason why they should not legally control the situation. Their attitude toward the matter, as noted by an unbiased observer who has probably had a better opportunity to appreciate the status of affairs as they really exist, leads to the belief that the upholding of their patent rights will not bring into existence any restrictive monopoly. This has already been amply demonstrated by their full permission for the employment of their device in experimental work.

What they have attempted to stop has been merely the manufacture of machines alleged to infringe their patents for sale and exhibition purposes—in other words, the making of money by means claimed to have been made possible through the utilization of their ideas, whether in the same or a modified form. In brief, the legal steps taken thus far are as follows:

The patent which embodies the Wright flying machine was issued May 22, 1905. In the latter part of 1909, the United States Circuit Court was appealed to to enjoin the Herring-Curtiss Company and Glenn H. Curtiss from manufacturing, selling, or using for exhibition purposes, the Curtiss aeroplane. Contrary to established precedent in patent litigation, Judge Hazel, of the United States Circuit Court in Buffalo, granted a preliminary injunction restraining the defendants mentioned. The chief question at issue in this instance was whether or not movable auxiliary surfaces, popularly termed ailerons, or wing tips, constituted an infringement of the Wright patent. The court reviewed the Wright patent at some length, but in its opinion the question of infringement as between warping and the use of ailerons is the only one of importance existing at present. On this, Judge Hazel said:

> Defendants claim generally that the difference in construction of their apparatus causes the equilibrium, or lateral balance, to be maintained and its aerial movement secured upon an entirely different principle from that of complainant; that defendants' aeroplanes are curves firmly attached to the stanchions and hence are incapable of turning or twisting in any direction; that the supplementary planes or so-called rudders are secured to the forward stanchion at the extreme lateral ends of the planes and are adjusted midway between the upper and lower planes with their margins extending beyond the

edges; that in moving the supplementary planes equal and uniform angles of incidence are presented as distinguished from fluctuating angles of incidence, which claimed functional effects, however, are strongly contradicted by the expert witness for complainant. Upon this contention, it is sufficient to say that the complainant's affidavits so clearly define the principle of operation of the flying machine in question that I am reasonably satisfied there is a variableness of the angle of incidence in the machine of defendants which is produced when a supplementary plane on one side is tilted or raised, and the other simultaneously tipped or lowered. I am also satisfied that the rear rudder is turned by the operator to the side having the least angle of incidence and that such turning is done at the time the supplementary planes are raised or depressed to prevent tilting or upsetting the machine.

On the papers presented, I incline to the view, as already indicated, that the claims of the patent in suit should be broadly construed; and when given such construction, the elements of the Wright machine are found in defendants' machine performing the same functional result. There are dissimilarities in the defendants' structure—changes of form and strengthening of parts—which may be improvements, but such dissimilarities seem to me to have no bearing upon the means adopted to preserve the equilibrium, which means are the equivalent of the claims in suit and attain an identical result.

Defendants further contend that the curved or arched surfaces of the Wright aeroplanes in commercial use are departures from the patent which describes "substantially flat surfaces," and that such a construction would be wholly impracticable. The drawing attached to the specification, however, shows a curved line inward of the aeroplane with straight lateral edges, and considering such drawing with the terminology of the specification, the slight arching of the surface is not thought a material departure. At any rate, the patent in issue does not belong to the class of patents which requires narrowing to the details of construction.

The preliminary injunction restraining Curtiss was accordingly granted January 3, 1910. About the same time the United States Circuit Court for the Southern District of New York was appealed to to restrain Louis Paulhan, the French aviator, from using a machine, claimed to infringe the Wright patents, for exhibition purposes in this country. Paulhan contended that it would be suicidal to interconnect the operating control of the ailerons and the direction rudder; that either may be and is used independently of the other; that the use of the rudder alone will prevent "skidding" and restore the aeroplane's equilibrium; and that complete turns may be made without employing the ailerons or warping the wings. An excerpt from Paulhan's statement on this point is as follows:

In turning a corner in the Farman biplane, or any aeroplane with which I am familiar, it is not at all essential to use the aileron to increase the angle of incidence on the outer edge. There are circumstances in making a turn in

> such machines and in straightaway flight when the operator would use the aileron or warp the wings without turning the rudder at all, and very often the rear vertical rudders are used without any interference with the ailerons.*
>
> If for some reason such aeroplanes move obliquely to their longitudinal axis, *i.e.*, "skid," the use of the rudder alone will correct the aeroplane's equilibrium and bring it back to its normal line of advance. The operator can make a complete turn by the use of the rear vertical rudders alone and without using either ailerons or warping to correct horizontal equilibrium. The rear vertical rudders have a most powerful turning effect in all cases. In making a sharp turn the outer end of the aeroplane may be tilted up and a new plane of movement established which may be at an angle of ten or more degrees. The tendency of the rudder during such movement is to swing the tail to the outer side of the turning arc with great rapidity. Where one side of the Farman biplane is depressed or tilted downward, that side tends to move more slowly and the aeroplane turns in the direction of the depressed side.

These statements represent a condition so utterly contrary to what the Wright Brothers had experienced in all their experiments as absolutely essential to flight, that they invited Paulhan to substantiate his theories in flight in their presence, making his ailerons fast so that they could not be moved. It is believed that some of these test flights were actually carried out, but what their result was does not appear. At any rate, Judge Hand granted a preliminary injunction to the Wright Brothers against Paulhan on February 17, 1910, requiring the defendant to file a bond for $25,000 for one month's flights. This was shortly afterward changed to $6,000 a week.

The most significant part of Judge Hand's opinion, which was lengthy, throws considerable light on what he considered the invention to consist of, and also illustrates what is regarded as the status of the numerous prior patents which are claimed to anticipate the Wrights'. After referring to the Ader machine in which there was a provision for warping the planes, he says:

> The mere coincidence of these parts by chance or as a matter of taste was in no sense an anticipation of their functional correlation, in understanding which the complainant's discovery consists and with it their invention.

In fact, the Wright Brothers state in their application:

> We are aware that, prior to our invention, flying machines were constructed having superposed wings in combination with horizontal and vertical rudders.

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*Provision is made in the Wright machine for independent use of either warping or vertical rudder, as the controlling lever may be moved in one or both directions at will.—Ed.

Some of the more important patents upon which the claim of anticipation is based are the Mattullath patent, application filed January 8, 1900; the Boswell patent dated September 24, 1901; and the machines of Mouillard, Le Bris, and Ader, discussed in Chanute's "Progress of Flying Machines."

At a time when the controversy is at its height, it is naturally difficult to reconcile the innumerable conflicting statements and the maze of contradictions that exist. Where what is known as the "prior art" is concerned, however, it would appear quite probable from a statement occurring in an opinion handed down by the United States Circuit Court of Appeals in New York, that earlier patents will be disregarded where they have not been shown to be operative, which would naturally exclude practically every patent granted prior to May 22, 1906. The action in question was in regard to a railway signal, the reference in the opinion being by way of illustration of the principle that a patent for a useful device will not be held void because of an earlier patent for a useless device.

> Success can not be anticipated by failure. When the problem of aerial navigation is finally solved by the construction of a secure, dirigible airship, it is safe to predict that the inventor's patent will not be invalidated by a prior structure, no matter how perfect it may be, which was never known to fly.

As already mentioned, it was quite contrary to precedent to grant a preliminary injunction restraining an alleged infringer before the patent was actually adjudicated, *i.e.*, upheld in an action to test its validity, so that in vacating the injunctions against Curtiss and Paulhan about six months later, the Circuit Court of Appeals simply followed the long-established precedent of American patent law. As a general rule, preliminary injunctions are not countenanced in patent cases, even by the lower courts. It seems evident upon reading in full the opinions of the lower courts in this case, and particularly that of Judge Hazel, that the court was led to disregard precedent through what appeared to be the clearness of the case of infringement of a basic patent of far-reaching importance.

The reason why preliminary injunctions are so rarely issued is because seldom, indeed, is infringement so clearly established that a court is justified in restraining the use and manufacture of an invention before the question of patent validity is decided. The hardship which results from too great a readiness on the part of a lower court to restrain an alleged infringer is strikingly illustrated by the injunctions issued against Curtiss and Paulhan. As a result, the Wright Brothers controlled aviation in this country (*i. e.*, exhibition flights, manufacture, and sale of machines) absolutely for half a year. Unless he filed a bond with the court, no aviator, using a machine equipped with ailerons or wing-warping devices operated in conjunction with a vertical rudder, could make, sell, or fly his apparatus in the United States.

But that there appeared to be excellent reason for departing from established precedent in this instance must be plain to anyone who has had an opportunity to review the correspondence that passed between Curtiss and the Wright Brothers prior to the time that Curtiss began to build or exhibit machines for profit. Curtiss was assisted to a considerable extent in the design and construction of his machine by the Wrights, and acknowledges his indebtedness to them for information of this nature as well as for valuable data. When it was rumored that Curtiss was about to enter the commercial field, the Wright Brothers voluntarily offered to take up the question of a license to use their machines, but Curtiss replied under date of July 24, 1908, that, contrary to newspaper reports, he did not expect to do anything in the way of exhibitions. This correspondence was all placed in evidence in support of the petition for the injunction, and it was further shown that Bleriot did not apply anything in the nature of the present method of control until subsequent to the publication of the French Wright patent in 1904. In fact, Captain Ferber, who is regarded as the leading French authority on aviation, states in his works that the art was only taken up in France as the result of the publication of the Wright Brothers' early experiments in Europe. There has seldom been a case in patent litigation where infringement of a sound basic patent was apparently so clearly made out, so that it was difficult to see how the court could refuse to grant the injunction under the circumstances.

The vacating of these injunctions accordingly forms no criterion of the final outcome, as no trial on its merits has yet been held. The Circuit Court of Appeals merely held that infringement was not so clearly established as to justify a preliminary injunction. A trial of the action against the Herring-Curtiss Company for infringement was therefore begun, and other similar actions have since been instituted, notably that against Claude Grahame White, the English aviator. When this action comes to trial, Henri Farman promises to produce several heretofore unknown foreign patents which he has acquired and which are claimed to clearly anticipate the Wrights'. Meanwhile the Farman Brothers are threatening to prosecute all infringers of the several patents they hold in common. In view of the opinion of the Circuit Court of Appeals cited above, Farman's patents would not appear to be of any great value as evidence in this country, as they naturally do not cover a machine that actually flew before that of the Wright Brothers. The German Wright patent has recently been upheld in part, although the basic feature in regard to the simultaneous action of the rudder and wing flexing has been invalidated.

Under the laws of Germany and France, a disclosure of an invention by the inventors, or by anyone else who has knowledge of it, before the application for a patent is filed, is sufficient to render the patent void. Such disclosure must be sufficient to enable anyone to understand how to build and use the invention. The revelation of the invention upon which the German patent office based this decision were citations from *L'Aeronaut*, Paris, April, 1903, giving a report of the address of Chanute describing the Wright experiments at Kitty Hawk in 1902, and from *Automotor*, London, February 15, 1902, giving a synopsis of the address of Wilbur Wright before the Western Society of Engineers in 1901, describing their experiments of that year. The statement of Chanute which is cited as a disclosure of the Wright invention was as follows:

"To assure transverse equilibrium, the operator works two cords, which warp the right and left wings and at the same time adjust the vertical rear rudder."

The German Patent Office has taken the extreme position that these few words were sufficient to teach anyone how to build and operate a flying machine in 1903, and that they canceled the right of the inventors to any property in their invention in Germany. The Wright Brothers do not believe that this decision is based upon a proper interpretation of the law and have appealed to a higher tribunal, as noted. From the report of the French decision given further along, it will be apparent that the French court took a far more liberal view of this aspect of the case. The court upheld two specific forms of patent, combining the steering and flexing. In Germany, patent procedure is the reverse of what it is here—a patent is presumed to be valid from its date of issue until proved to the contrary. Accordingly, five German firms formed a syndicate and brought suit to have the Wright patent declared of no value, with the result mentioned. This decision is by the Patent Office and judgment is open to appeal before the Imperial Supreme Court at Leipzig, action to this effect having been taken.

In France, Le Compagnie Generale de Navigation Aerienne, the sole French concessionaires of the Wright patents, brought actions against more than half a dozen prominent manufacturers and inventors, such as Bleriot, Farman, Antoinette, Clement-Bayard, Esnault-Pelterie, Santos-Dumont, and others. Santos-Dumont alone withdrew all defense, and, curiously enough, he is the only defendant in whose favor judgment was rendered, on the ground that his was the only aeroplane that was not built for purposes of trade or private gain.

The types of aeroplanes involved were the Antoinette and Bleriot monoplanes with warping wings, the Farman with ailerons or "flaps" at the rear lateral margins of the planes, and the Hautier-Vendome with ailerons at the front edges of the wings. A large part of the decision relates to matters of French law which renders patents invalid under certain conditions, such as failure to work an invention within three years of the time of applying for a patent, and the revelation of an invention before patenting it. The decision was in favor of the plaintiffs in all of the cases except that of Santos-Dumont, as mentioned, but before rendering final judgment, the court gave the defendants a final loophole through which to crawl, if possible, by appointing a committee consisting of M. Léauté, Major Paul Renard, and Marcel Deprez, to determine whether the Wright patent of March 22, 1904, had not been anticipated by some machine unknown to the defendants at the time of the trial. The court said in part:

> If the action in pursuit of a claim is established in principle, it is subordinated to the double question of knowing if there has not been one or more priorities of all the parts opposed to the patent of 1904, and if, on the other hand, it will not be found void as against certain of the defendants, as they may have made an entirely new adaptation of the mechanical means pointed out by the Wrights for the re-establishment of the lateral equilibrium, and of which they shall have conceived a structural means constituting in connection with the patented invention an invention entirely new and original.

But on this point, a writer in the official organ of the Aero Club of France, which completely controls aviation in that country, says:

> The mission given to the experts is singularly limited, and does not allow the defendants any hope of emerging victorious from the contest. So one should not be astonished that many of the defendants already express an intention of appealing from a judgment which they consider so disastrous to them.

In the trial of the action the plaintiffs alleged that the Wright patent, being their personal property, gives them the right to claim not only the joint and separate action of the mechanism of the rear direction rudder and the variation of the angles of incidence (to wit, the combination), but separately, each of the elements of this combination in so far as it is employed for the result provided for, that is, for the re-establishment of the lateral equilibrium and the maintenance of the direction of flight. Wilbur Wright was present and testified in person.

The main points of defense presented were: That the Wright patent was not valid because (1) the Wrights had revealed their invention before applying for a patent; (2) they had not worked the invention within three years; (3) the invention was known to the prior art. Further, that the defendants did not infringe the patent, which gives the plaintiffs only the property of the combination employed, and not the distinct elements which are employed separately and independently for the same purpose, elements which they claim are public property.

The claims of forfeiture were rejected by the court, the substance of the decision, stripped of its Gallic verbiage, being as follows:

(1) That the subject of the Wright patent of March 22, 1904, was patentable.

(2) That it was impossible to keep an invention of this nature entirely secret, and the photographs and descriptions published were not sufficient to invalidate it.

(3) That the Wrights were the first to fly, some of the defendants having claimed that flights had been made in France in 1898, and that they had invented the system of control that makes flight possible.

(4) That the patent had been worked in France as soon as possible under the circumstances.

(5) That the patent was valid.

(6) That the independent operation of the wings and rudder as used by the French was not sufficiently claimed in the Wright patent, and that, therefore, the French machines were not infringements of the latter. (This is apparently a "joker" that entirely offsets any value the decision might otherwise have, but this part of the decision is that of a "substitute judge," a technical expert whose services are required by the French law to advise the courton technical matters, and it was subsequently overruled by the court itself.)

The court, composed of three judges, confirmed the above findings with the exception of No. 6, on which point it stated that:

> While the independent operation of the wings and rudder was not specifically claimed in the words of the patent, yet the independent operation of the parts could not be considered as a new invention, but simply as an improvement in detail of the original invention, and that the patentees of the original invention were entitled to the benefits to be derived from it.

By referring to the descriptions of standard machines it will be noted that none of the French defendants were makers of a type in which the ailerons or controllable stabilizing devices were entirely separated from the main supporting planes, as is the case in the Curtiss, in which the ailerons are placed between the main surfaces of the biplane. All the French makers built infringing types of monoplanes, with the exception of Farman. This is practically the sole point upon which the entire Wright vs. Curtiss action hinges, and in view of the fact that it seems probable the United States Court will extend the construction of the patent to cover the use of separate ailerons as being an application of the same principle, the following resumé of the opinion of the French court is both valuable and instructive:

> Considering the point once established that the separation of the two elements claimed is a type of improvement, this separation ought to be considered as an appurtenance of the patent of 1904, that the improvement is a natural development of the primitive invention from which it can not be separated, and that proceeding from the master idea which is the generator of it, the patentees should have the right to profit by it. Of what little importance, then, is it, that in 1907 the Wright Brothers took out two other patents in which the independence of the warping and of the directing rudder was expressly provided, except that the combination of the two elements could be, if desired, effected by the hand; admitting that these two patents of 1907 repeat in certain parts the things which can be found in the patent of 1904 and that even these improvements in detail which were then meant to be patented were without importance, they would not have in them, to say the least, any utility as patents of extension.

It will be noted that the Court reversed the opinion of the "substitute" on the only point which he found in favor of the defendants. In reversing this point, that the independent operation of the wings and rudder circumvented the patent, the Court said:

> In the patent of 1904 the connection of the warping device with the rudder is so minutely described that it can be understood and applied by engineers and constructors of aeroplanes; there is no reason to believe that the Wright Brothers should have made a more general claim and should have claimed each of the elements, taken separately, but they should be confined to the limits which they have described in the patent.
>
> After the patent of 1904 the invention consisted in a method of maintaining or re-establishing the equilibrium of the aeronautic apparatus and of guiding the machine in a vertical or horizontal direction. Among other elements the patent provides (1) the existence of two horizontal surfaces or wings, consisting of a frame on which fabric is spread, and connected one to the other by means of posts and articulations, which permit of movements of torsion and flection of the ends of the wings in opposite directions; (2) of a vertical rear rudder, connected to the cables that produce the torsion of the ends of the wings.
>
> The combination of the two elements is well within the scope of the patent. It says in lines 14 to 19, page 3:
>
> *By this means of attachment the same movement of the cables which actuates the ends of the wings, also presents to the wind that side of the vertical rudder which is turned toward the end having the smaller angle of incidence.*
>
> In vain the suing company cites two other passages of the description. The passage from the 34th line to the 43rd line of the third page does not say that the rudder can be independent; nor is the passage from the 45th line to the 57th line more explicit:
>
> *This invention is not limited to the construction and attachment of the rear rudder herein described, nor to this particular construction of surfaces or wings, for one can employ this combination in the use of any movable rear rudder operated in conjunction with any wings capable of being presented at different angles of incidence at their opposite ends, for the purpose of restoring the lateral balance of a flying machine and of guiding the machine to right or left.*
>
> The words "actuate at the same time," about which so much has been argued, can be interpreted only in the sense that there is a device which permits of the movement of the two commands at the same time. This point once established, the disassociation of the elements claimed is a type of improvement.
>
> This disassociation must in principle be considered as a dependent of the patent of 1904, since this improvement is a natural development of the primitive invention, proceeding from the master idea in which it had its origin, and from which it can not be separated. The patentees alone have the right to profit by it.

The outcome in this country appears to depend entirely upon whether ailerons or wing tips—independent auxiliary surfaces between the planes, as in the Curtiss, or hinged extensions of the wings themselves, as in the Farman—really constitute an infringement on the principle of actually warping the surfaces of the wings themselves. This may be gathered from the following concise statement of claims 1, 2, 3, 4, and 7 of the Wright patent. The specifications are drawn to cover monoplanes, biplanes, and machines having two or more superposed surfaces.

> 1. In a flying machine, a normally flat aeroplane having lateral marginal portions capable of movement to different positions above or below the normal plane of the body of the aeroplane, such movement being about an axis transverse to the line of flight, whereby said lateral marginal portions may be moved to different angles relatively to the normal plane of the body of the aeroplane, so as to present to the atmosphere different angles of incidence, and means for so moving said lateral marginal portions, substantially as described.
>
> 2. The application of vertical struts near the ends and having flexible joints.
>
> 3. Means for simultaneously imparting such movement to said lateral portions to different angles relatively to each other.
>
> 4. Refers to the movement of the lateral portions on the same side to the same angle.
>
> 7. Means for simultaneously moving vertical rudder so as to present to the wind that side thereof nearest to the side of the aeroplane having the smallest angle of incidence.

As will be noted in the opinion of Judge Hazel, the Wright patent will undoubtedly be construed broadly and not narrowed down to constructional detail so that the reference to "flat planes," of which much was made in the briefs of Curtiss and Paulhan in their defense of the injunction proceedings, will probably not affect the decision in itself. Both defendants strongly contended that a machine with flat planes would be entirely impracticable, *i.e.*, an inoperative device, thus maintaining that the present Wright machine is not the apparatus described in their patent. This is a point of the greatest importance and has been the means of declaring patents invalid that would otherwise have been of considerable value, such as the patent on clincher tires for automobiles. Some of the more recent high-speed racing machines built in France during 1911 have been equipped with supporting surfaces that are almost flat or at least sufficiently so to substantially fulfill the requirements of this claim of the patent under the broad construction accorded it.

This accordingly confines the points at issue to whether supplementary surfaces, either independent of or attached to the wings themselves, constitute an infringement of the warping device of the Wrights, and whether the simultaneous operation of the vertical rudder in conjunction with these supplementary surfaces, regardless of how it may be carried out, is an infringement of the functional correlation of these parts which Judge Hand states constitutes the invention of the Wright Brothers.

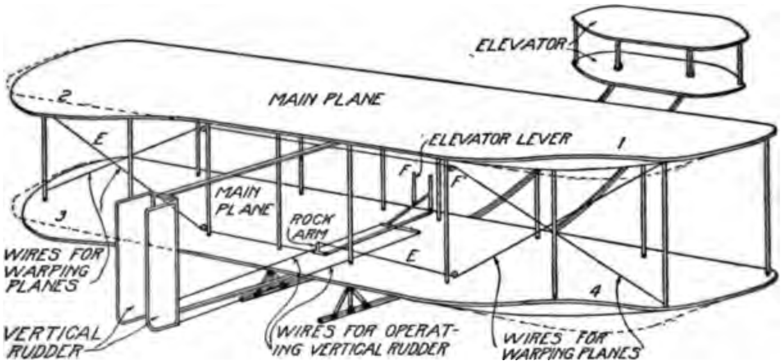

Fig. 40. Diagram of Wright Control System, Showing Warping of Main Planes

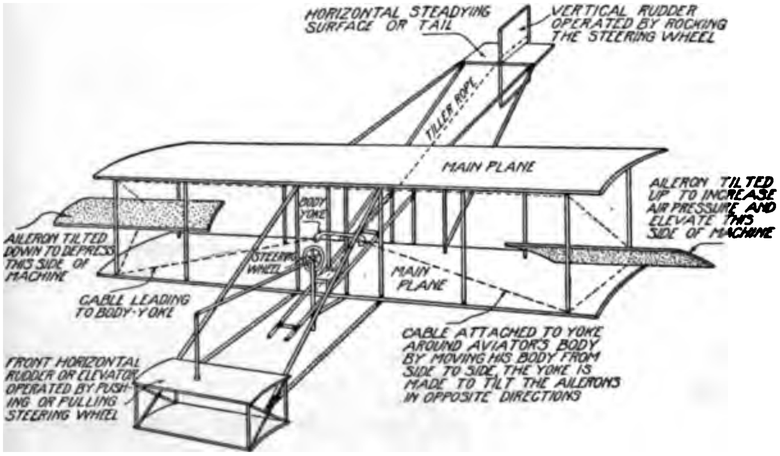

Fig. 41. Diagram of Curtiss Control System, Showing Use of Ailerons Swung between Main Planes

As shown by the drawing, Fig. 40, the Wright machine is provided with means for operating the vertical rudder in conjunction with the warping of the main planes, as covered by claim 7 of the patent. Ability to move the hinged lever on the machines in actual use in two directions makes it possible to use either control independently or both simultaneously.

Fig. 41 shows that these controls are separate in the Curtiss machine, but they naturally can be employed simultaneously by the aviator. The Farman system of control is shown in Fig. 42, and the Bleriot in Fig. 43. The Wrights regard it as basic that both controls be carried out together to attain successful flight, Wilbur Wright explaining the operation of turning as follows:

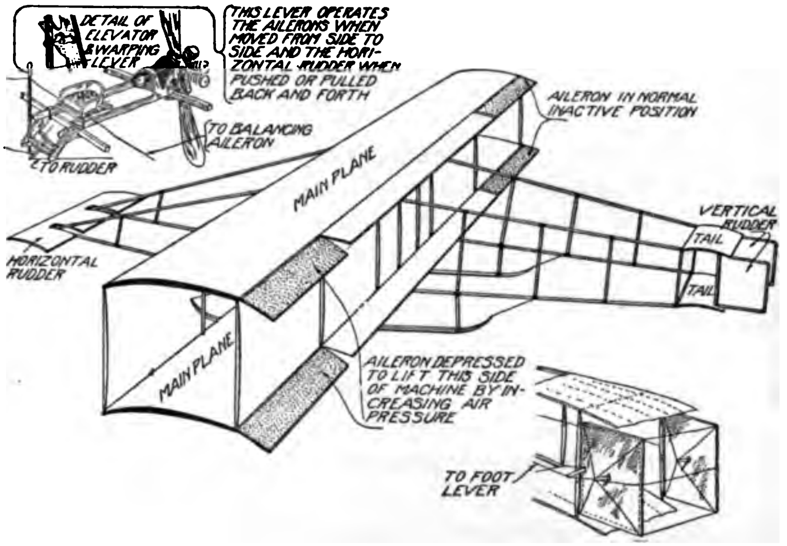

Fig. 42. Farman System of Control, Showing Use of Ailerons Attached to Main Planes

> In making a turn to the left, the left side of the machine would slow up and the right side would move faster. If only the vertical rudder were employed to make the turn, the machine would skid greatly to the right, headway would be lost and, at this point in the turn, the machine would tend to stand on its right side, lose support, and drop. To make a short turn to the left without losing headway, the practice is to warp the right-hand end of the plane down and the left-hand end up, with vertical rudder turned to the left, it being necessary to heel the machine to the left to prevent skidding.

It is claimed to be possible to make turns of great radius without warping the wings, but the machine would skid more or less and, moreover, would not be entirely safe. Its stability would be precarious. In making a short turn without the use of the vertical rudder in conjunction with the warping of the wing ends, the machine tends to turn on a vertical axis like a corkscrew, and the simultaneous operation of both essentials is necessary to overcome this.

In view of the flatly contradictory statements made in the briefs submitted in the injunction proceedings, the frank opinion of Louis Bleriot, France's foremost aeroplane designer and builder, contained in a letter written regarding the granting of the injunction against Paulhan gives an inkling of what the views of other unprejudiced inventors in the field really are:

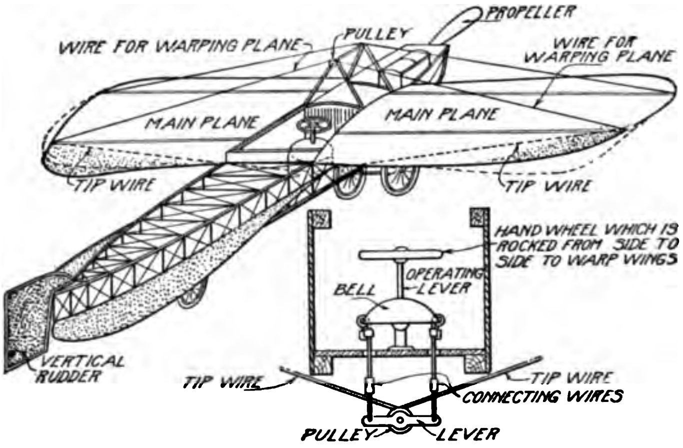

Fig. 437 Bleriot Control System by Warping of Main Plane

> Concerning the Wright patents my opinion is that the warping of the wings, taken in itself, is public property, and I think this can easily be shown. The vertical rudder is itself public property and it is only the combining of these two effects—balancing and steering—in a single lever control which can with some show of reason be claimed by the Wright Brothers. I have personal reason to regret that they did not confine their claim to this single lever, for it is an interesting improvement and one concerning which we could have established an understanding with the Wrights that would have been of profit to all aviators.
>
> In all my present French machines, the warping of the monoplane surface is brought about with the left hand, while the steering is dependent on

foot control. These two effects are entirely independent and in no way necessarily corrective, as called for in the Wright patents; on the contrary, experience shows that the major part of the time their effects should be added to each other instead of being corrective of each other. *This independence of control necessitates a somewhat more delicate hand and a longer apprenticeship,* but one which the present uncompromising attitude of the Wrights forces me to maintain.*

I have gone further: In view of their threats I have tried to do away completely with warping, using only for balancing purposes a somewhat larger vertical keel.† The result was entirely satisfactory: I was in this manner able to fly without warping, in winds as strong as those faced by the Wrights. I delivered to Paulhan two such machines for his American trip and, in his trials at Pau prior to leaving France, he flew perfectly without any warping device. He made as sharp turns as previously and merely had to use a greater tilt when doing so.

To sum up: This question of warping about which so much fuss has been made, and which seemed to be a *sine qua non* condition of lateral stability, proves to be of far less importance. If warping renders signal service in keelless machines of wide wing area such as the Wright machines, it becomes a far less necessary improvement in machines of small breadth of wing, provided with keels, and is entirely needless in machines with vertical partitions, such as the Voisin biplanes. As aeroplanes will tend more and more toward increasing speed and diminution of breadth of wing, the question of warping will more and more lose its importance.

I merely wish to say that it was regrettable to see at the dawn of a science (to encourage which all should have united in their efforts), inventors make the unjustifiable claim of monopolizing an idea, and, instead of bringing their help to their collaborators, prevent them, for no reason, from profiting by some ideas which they should have been happy to see generalized.

It is apparent that M. Bleriot is laboring under the same erroneous impression regarding the threatened monopoly as are other aviators, many of whom have reason to be well informed. That this monopoly will not come, even after the Wright patent has been declared valid, may be seen from the statement of their counsel, H. A. Toulmin, made in answer to the endless criticism aroused by the granting of the preliminary injunctions early in 1910.

The Wright Brothers have repeatedly announced their willingness to license not only individuals who wish to fly with the Wright type of machine, but also to license exhibition managers, committees promoting exhibition meets and, in fact, anyone who wishes to use for any purpose a Wright machine or an infringing machine. Indeed these gentlemen have, to my knowledge, extended a helping hand again and again to other experimenters. They have

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*This statement is directly contrary to Berget's claim—"Conquest of the Air,"—that the French machines may be controlled by amateurs after a few flights; whereas the Wright machine requires a long apprenticeship.—Ed.

†See descriptions of special types of American machines on same plan.—Ed.

supplied them with valuable data worked out by themselves, that other inventors might produce different and better machines if they could. This very fact was alluded to in the learned opinion of Judge Hazel in suit against the Herring-Curtiss Company. The Wrights have gone so far as to announce, and the fact has been published, that even though an experimenter were using a Wright machine or an infringing machine, he would not be molested so long as he confined his work to experimentation and did not seek to get money returns.

The chief development of importance during 1911, where the legal situation was concerned, was the granting of an injunction in favor of the Wright Brothers against Claude Grahame White, by Judge Hand, sitting in the United States Circuit Court for the Southern District of New York. So far as White personally is concerned, this settles the validity of the Wright patent, though where the patent itself is concerned, this does not alter its status. As the result of the injunction White can not fly in the United States without permission of the Wright Brothers, and if they do grant the necessary permission, he must either fly a Wright machine, or pay royalty on the one he uses, while the decision also opens the way for an accounting for the damages accruing from White's use of infringing machines from November, 1910, or even earlier, another action having been started for that purpose. The action, favorably ended for the Wrights by Judge Hand's opinion, was a suit for infringement and accounting by reason of the defendant's use of Farman and Bleriot machines in this country, claims 3, 7, 9, 14, and 15 of the Wright patent being involved. No proofs were presented by the defendant and the validity of the Wright patent was not seriously disputed. Judge Hand, among other things, states:

> In the form in which the case arises there can not be any substantial doubt of the right of the complainant to an injunction. The defendant has put in no proofs upon any of the issues raised in the answer and the patent is sustained by its own *prima facie* validity. I shall adopt the same interpretation which I put upon it in The Wright Company vs. Paulhan, and hold that the fixed connection between the rudder and the warping mechanism is not an essential feature of the claims, but that the only connection between the two may be made by the intermediation of a human body and a human will. The defendant, while not conceding the validity of the patent, does not seriously challenge it, or argue that his biplanes have not infringed it. I have, therefore, no alternative but to grant an injunction.

It may be another year or two before the Wright-Curtiss action, which is the only suit pending that has the validity of the patent as its issue, will be decided in the lower court, as further time has been granted in which to take testimony before it goes to trial in the United States District Court at Buffalo. As there will undoubtedly be an appeal, regardless of which of the litigants is favored with a decision, it may be several years before the patent rights of the plaintiffs are actually established.

During 1912, action is to be taken generally against makers and aviators in this country who are manufacturing and exhibiting alleged infringing machines. This is not the legal procedure originally planned by the Wright Company, but one that has been forced upon it, more or less, by public censure. The original intention was to bring infringement suits against makers or users of the principal types of machines, such as Curtiss, Farman, and Bleriot only, and to obtain as early an adjudication as possible for the benefit of the art and industry, for not until final confirmation or dismissal of the Wright claims would capital be likely to invest in aviation nor would the public buy machines of the types involved. The progress of the actions against Paulhan, against Curtiss, and against White has already been outlined. It is questionable, in case injunctions are granted, as would appear likely in view of the White decision, that damages could be collected from defendants permanently resident in France, though it seems probable that the English courts would favorably view the judgment of an American court and compel payment of the claims against White.

Criticism was quite general of the action of the Wrights in selecting the few defendants mentioned, and there was considerable wonderment as to why the Moissant aviators were not prosecuted, why Sopwith was allowed to import and fly machines in this country, and why Ovington, Baldwin, Willard, and the large number of lesser lights who are killing the prospects for future meets and exhibitions all over the country by failing to satisfy the public curiosity, or even to fly at all in some instances, were left to do as they pleased. Actions have accordingly been begun against many of the aviators in question and still others will be sued. The policy of the Wrights in this connection is made clear by the appended statement of F. H. Russell, general manager of the Wright Company.

> Our first desire was not to bother the general public until it could be informed as to the legal status of the Wright patent, but with such rapid

developments in this country, and with the coming over of foreigners who are not interested in development, excepting in so far as they would make money to take away from the country, we were becoming criticized for the very policy which we considered most broad and liberal. Then, too, by refraining from these further suits, we might be considered as acquiescing, to the detriment of our legal position.

Another reason, quite as important as the popular feeling (above expressed), which has altered our policy, is the fact that manufacturers and licensees in these exhibitions who have recognized our patents and paid our royalties, are very rightly requesting the protection in their business which they feel the patents should insure, and which they have paid for.

Legislation. The practical use of the aeroplane and the airship has brought with it new legal problems, which are now the subject of attention in several countries. In view of its leading position in this field, France has already taken the first step by adopting a code of laws to regulate aerial navigation in that country, the object being to protect the public against inconveniences and risks which may result from imprudent and daring aviators, quite as much as to regulate the users of the machines themselves. The code adopted comprises six chapters with forty-two provisions. It requires all "airships" (dirigible balloons or aeroplanes) to bear a visible registration number, and to carry a log book in which the names of all persons carried and the times and places of departure and arrival are entered. No explosives are to be transported except by special permit, while wireless and photographic apparatus is also prohibited without permission from the minister of public works. Flights over cities and crowds are prohibited and the airship must alight whenever officially signaled to do so, though just what the signals are to be has not been settled. Dirigibles must carry "sailing lights" between sundown and sunrise, exactly the same as in marine service, *i. e.*, a white headlight and red and green lights to port and starboard, respectively. Aeroplanes have been given temporary permission to carry a single light, but it must show white ahead and red and green to left and right, similar to the small combination motorboat lights used in this country.

However, American law is based upon the English common law and, as the latter differs radically from the French code, the situation in both countries where aeronautics is concerned is totally different. In view of the old legal maxim that ownership of the land extends to the center of the earth and to the sky, or in other words, indefinitely in both directions from the surface, there would appear to be no public right to the atmosphere at all. But no square decision has ever been made on this point, while the numerous dicta of which it has been made the subject would indicate that the maxim is rather lightly regarded, it having been referred to in one instance as a "fanciful phrase." But it is only when the possession of the soil is interfered with that the airman is likely to infringe upon the rights of property owners. That point of view is taken in most of the European codes. For example, in the German code it is stated that a property holder can not prohibit such interferences undertaken at such a height or depth that he has no interest in the prevention.

Probably the first laws to be enacted in this country will concern human safety and not property. In view of the accidents that occurred at Paris on the occasion of the start of the Paris-Madrid race in the summer of 1911, it seems unlikely that air craft in Europe will be permitted to fly over large cities or towns owing to the possibility of being compelled to descend because of a crippled motor or lack of fuel. On the other hand, the open country and navigable streams will doubtless be unrestricted.

Forced descents may perhaps render it necessary to treat the airman more leniently than is possible under the common law. In a New York case (Guille vs. Swan, 19 Johns. 381), decided in 1822, an aeronaut was held responsible not only for the direct damage caused by the descent of his balloon into a garden, but even for the consequential damage caused by the crowding of strangers upon the property to satisfy their curiosity. Governor (formerly judge) Simeon Baldwin of Connecticut reviewed the problem in an article in the *American Journal of International Law* (1910) in which he raised the question as to whether the law of self-preservation might not be invoked by the airman who is compelled to make an immediate landing to save his own life and in so doing accidentally causes the death of another. Under ordinary circumstances, he considered it advisable to indicate by some simple means where landing was prohibited and where permitted. As a matter of general policy it would not seem that the aviator should be made to pay more than for the direct damage for which he himself has been responsible.

To avoid these forced descents, and to insure as careful control of air craft as possible, licenses to navigate the air will undoubtedly be necessary. Most of the bills pending before State Legislatures in this country and which will probably be enacted generally during the next year or two provide for such licenses as one of their most important features. In this country, it is questionable whether the States should be permitted to issue such licenses in preference to the Federal Government, though attempts to have a law of this nature passed to control automobiles have extended over a number of years without success. With aeroplanes traveling anywhere from 40 to 90 miles an hour, several of the smaller States could be traversed in the course of a day. The conditions are so radically different and the distances covered so great that the present practice of one State recognizing the automobile licenses of others would mean the practical nullification of any State's license act. The right of the Federal Government to license air craft would appear analogous to that of regulating navigation on coastal as well as inland waters.

Questions of aerial international politics have already given congresses which have met in Europe no little concern but, on the whole, there appears to be a tendency to apply the principles of maritime law to air craft. The American Political Science Association has suggested that the right of the air craft of one nation freely to traverse the air space of another might be compared with that of the vessel of one State freely to navigate the waters of a co-riparian State. The abortive convention drafted by the International Conference on aerial navigation in 1910 was based entirely upon the provisions of international maritime law. There are the same requirements as to registration and nationality of the vessels, the same method of determining the fitness of the craft and the competence of its navigators, and the same regulations applying to the sojourn of air craft in distress. Provision is also made for the keeping of logs, customs supervision of the atmosphere, the right of police, the regulation of passenger and freight traffic, the prohibition of navigation in certain zones in the vicinity of fortifications; and there is even a tendency to incorporate a principle analogous to the three-mile neutral zone of maritime law, but there appears to be no agreement as to the height of the zone as yet.

Customs. Aeroplanes have also caused more or less trouble to the customs authorities of various countries, entirely aside from their adaptability to the dark ways of smugglers. For instance, Mexico classes the flying machine, when imported complete, under the head of "articles not specially mentioned of iron, steel, or tin plate, etc.," while Canada places the aeroplane in the same category as "telephone and telegraph instruments, batteries, motors, dynamos, and electrical apparatus not otherwise provided for." In India the Governor General is given authority to make regulations concerning the admission of aeroplanes, or to prohibit their importation entirely. The duty in this country on a complete machine is naturally affected by the fact that it is equipped with a motor, bringing it under the head of "manufactures of metal," which makes the rate on the entire machine 45 per cent *ad valorem,* substantially adding to the cost of a foreign machine in this country.

MILITARY IMPORTANCE OF AEROPLANE AND DIRIGIBLE

Whenever a new development receives a great impetus, as has been the case with aeronautics generally within the past few years, prophecies abound. The day when the aeroplane will be utilized in a similar manner to the automobile appears to be so far distant, at present, that the imagination naturally reverts to something more immediate—and that something has taken the form of the military importance of the aeroplane and the dirigible. Owing to the great expenditure involved in the construction and maintenance of the latter, its chief destiny appears to lie in this direction. When the submarine torpedo was perfected, prophecies to the effect that here, at last, was an instrument that would make war impossible in future, were freely made; the submarine boat and the Dreadnaught type of battleship met with similar acclaim. Despite the lack of fulfillment that has attended these prophecies, they have been dragged out again and made to serve in the same rôle for the aeroplane. As was naturally to be expected, much that is erroneous and misleading has appeared regarding the latter as well as its bulkier and more costly comrade-in-arms, the dirigible. That the "aerial navy," however, is already an established fact will be evident from the following, which represents the strength of this "new" arm of the various military establishments of the world.

Attitude of Military Powers. France maintains 4 dirigibles of an aggregate of 395 horse-power, and 38 aeroplanes, mostly of the monoplane type; Germany has 7 dirigibles of 1,160 horse-power, and 24 aeroplanes, mostly Wright biplanes of German manufacture; England has 3 dirigibles of 365 horse-power, and 3 aeroplanes, all biplanes; Russia has one 70-horse-power dirigible and 6 monoplanes; Italy has one 100-horse-power dirigible and 8 Bleriot monoplanes; Spain has one 100-horse-power dirigible and no aeroplanes; Austria has one 70-horse-power dirigible and 4 biplanes; and the United States maintains one Baldwin dirigible of 30 horse-power, and one Wright biplane. This brief statement gives some idea of the relative strength of the various nations at the end of 1910, and in the case of France plans had already been made to increase the equipment by more than 50 per cent, while in Germany activity in the same direction is also very much to the fore.* Japan and even Turkey are experimenting with both types of machines with a view to making them a part of their military service. The backwardness of the United States in this respect is explained by the great advantages of its natural position, but it is anticipated that more interest will soon be taken in an aeronautical division of the army, while experiments to make the aeroplane an auxiliary of the navy have already been undertaken.

Considerable interest has been aroused, however, by the successful flights of an aeroplane from the deck of a cruiser to the shore, and by the unusual feat of alighting on a specially-built platform on a man-of-war and again leaving it. The flights of Curtiss in a machine designed to alight on or run over the surface of the water have added to the interest, so that Congress has been induced to appropriate the sum of $125,000 for further experiments along this and similar lines, it being apparent that the aeroplane will be of great importance as an auxiliary to the navy, Fig. 44. Owing to the ease with which a machine can be taken apart and put together again, it can be stowed in a very limited space and can be quickly assembled for action. As the deck of a vessel, however, would not afford sufficient unencumbered space for either starting or alighting, it is quite evident that the aeroplane evolved for this purpose will be one capable of starting from the water and alighting on it—or rather one that is able to run and alight on either water or land.

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*These figures have since been greatly increased. France has placed large orders for aeroplanes and dirigibles. England and Germany are also increasing their aerial "navies," while the United States has acquired additional Wright and Curtiss biplanes, also Curtiss hydroaeroplanes, but it is difficult to give definite figures.—Ed.

England, also, is awakening to the importance of the new arm, but appears to lean somewhat to the German view which at first regarded the dirigible of paramount importance, though Germany has since greatly increased her aeroplane fleet. During 1910, there was constructed at the ship-building plant of Vickers' Sons & Maxim, Barrow in Furness, England, a huge dirigible for military purposes. The greatest secrecy was maintained regarding the details, but it was planned to be the largest dirigible ever attempted, exceeding in size any of the Zeppelin monsters thus far constructed. It was known

Fig. 44. The New Naval Scout the Fourth Military "Arm"

as Naval Airship No. 1 and was equipped with motors of 400 horsepower. The envelope was covered with a metallic coating to serve as a protection and to make the gas bag rigid. It had a carrying capacity sufficient to take a complement of 34 men, but at first only six officers and men were required, a special crew being in training to man it under expert supervision. The armament consisted of a special type of aerial weapon. A second-class cruiser was assigned to special duty as a convoy for the huge airship, but the latter was wrecked the first time an attempt was made to take it out of its shed. The length of this huge dirigible was 510 feet, the diameter at the greatest girth was 48 feet, and the gas capacity was 706,336 cubic feet. The envelope was made of silk and was divided into seven sections.

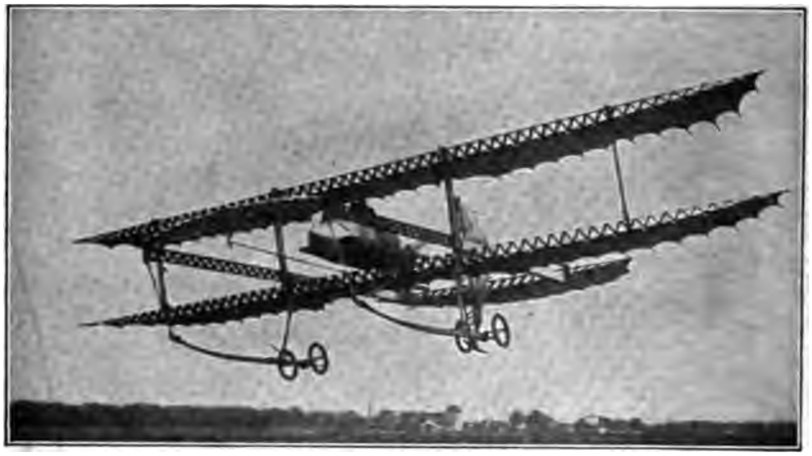

Fig. 45. Paulhan's All-Steel Aeroplane for Military Use

Power was derived from two sets of eight-cylinder, V-type, water-cooled, four-cycle Wolseley engines, designed to run at 500 r. p.m., driving three propellers which were expected to give the airship a speed of 45 miles an hour—a rate of travel not hitherto approached. To each of these engines was connected eight sheet-metal tanks, each tank having a capacity for 2,000 gallons of gasoline, making a total fuel capacity of 32,000 gallons. These tanks were welded together in airtight sections, insuring the ability of the airship to keep its motors running should an accident or injury occur to any particular section. The precaution, however, entailed the addition of 300 yards of aluminum piping for the connections. The framework was constructed of duralumin, a new alloy of aluminum which is said to be much lighter and stronger than that at present in general use.

The British War Department has also lately purchased one of the new type of aeroplane, Fig. 45, designed by Paulhan and described in detail later.

Adaptability to War. In most of the prophecies on the subject the use of air craft in war is regarded as being something quite novel and of entirely recent development. This, of course, is true of the aeroplane, but ever since Napoleon formed the first military balloon corps in 1793, practically all the first-class powers have utilized aeronautics in war to the extent to which development permitted at the time. Napoleon used balloons in Egypt, though with small success; the Austrians employed them before Venice in 1849, the Russians at Sebastopol in 1854-55, the French in the Italian campaign of 1859, the United States army in the Civil War, the French during the Siege of Paris, 1870-71, the British in the Indian and African campaigns, and both sides in the Russo-Japanese War.

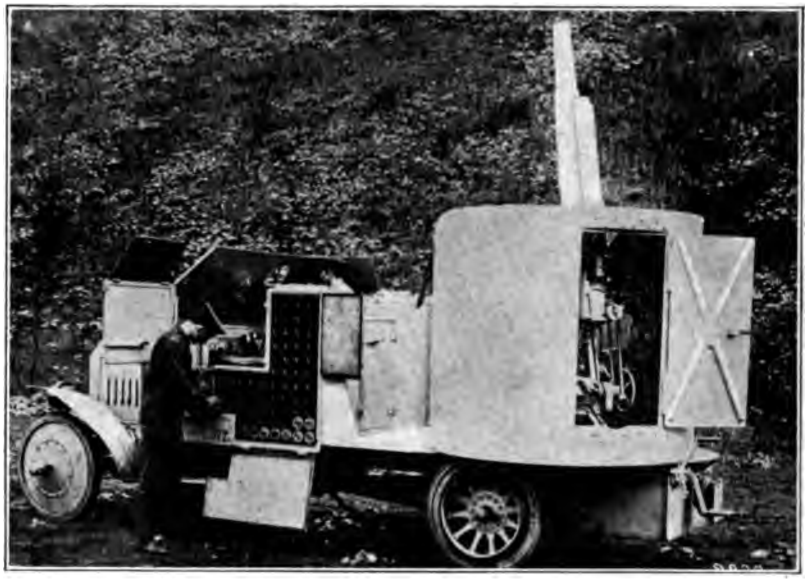

Fig. 46. Krupp Guns for Protection Against Air Crafts, Showing Open Ammunition Magazines

At first, the captive balloon was used altogether for scouting purposes, but since the advent of the dirigible the simple balloon has become obsolete for anything but purely sporting purposes. Up to two years ago, the relative importance of this arm of the service depended entirely upon the number of dirigible balloons maintained, and artillery designers have been very active in adapting their guns to firing at angles never before thought necessary. This has been the case particularly in Germany where the Krupp works have been conducting a series of experiments in firing at balloons with specially-designed guns, some of which are shown in Figs. 46 and 47. In addition to scouting, or rather discovering the enemy's position without endangering men in the latter service, the balloon has most frequently been employed for directing artillery fire, it having proved particularly valuable for this purpose both in our own Civil War, and in the Boer War in South Africa where a captive balloon was equipped with a searchlight and used at night. The history of its employment, however, may be found in detail in works on the subject and would be out of place here, except as a precedent for the development that is now taking place.

Fig. 47. Krupp Guns for Protection Against Air Crafts

The rapid development of the aeroplane and its facility of action more than justifies its ever-increasing application to military operations by the first-class powers. Such feats as Roll's return trip across the English Channel, Chavez's flight over the Alps, Tabuteau's six-hour flight, Breguet's flight with twelve passengers, McCurdy's sending wireless telegrams from a Curtiss biplane while in flight, Moisant's trip through country totally new to him by compass guidance, McCurdy's trip from Key West to Havana, and Ely's flight from a cruiser to shore and back are all accomplishments that could be put to considerable advantage in a state of actual warfare. Behind all the imaginative prophecies of airships eliminating navies, decimating armies, and utterly destroying forts and cities by dropping explosives, there is a foundation of fact which will be utilized as developments warrant it. All of the extravagant stories of the absolute invincibility of the aeroplane have not been the product of untrammeled creators with ample imagination, though the persistence with which they have been repeated has led to replies in kind which have shown a scarcely higher appreciation of the true value of the aeroplane. Even such a high authority as the late Rear Admiral Robley D. Evans is reported to have expressed an opinion that strikingly reveals how little is really known concerning the possibilities of the aeroplane.

It is only natural that those experienced in the service should express contempt for anything lauded as being so infinitely superior to the methods of warfare in which they are skilled. Nor is it anything new—the advent of the torpedo and the submarine boat brought forth a similar greeting. Some of the stories regarding the possibility of annihilating battleships and armies through dropping explosives on them were hardly worthy of anything better. It is a matter of common knowledge that to do any great damage, an explosive must be confined. An aerial bombardment could scarcely be expected to do as much damage as a naval action of the same class, and it would be far more difficult to carry on. There could be no penetration to the missiles and their damage would be confined to blowing holes in the surfaces of streets and the roofs of houses, or in the case of a man-of-war, in damaging its superstructure. Talk of this nature in connection with the destruction of battleships led Rear Admiral Evans to attempt to show how easily an aeroplane could be destroyed from the deck of a ship, Fig. 48. According to his theory, firing could begin at long range—say, 10,000 yards, or between five and six miles. As the machine approached, more guns could be utilized, and the aviator who would have the daring to approach a battleship under such a hail would be daring indeed.

But anyone who has seen an aeroplane at a distance of five to six miles can fully realize that nothing short of a miracle could ever cause it to be struck. It is the merest speck in the sky, even at a mile or so, and can best be compared to the size of a common housefly a hundred yards away. It is almost impossible to follow it with the eye, and once lost it is extremely difficult to pick up again. Add to this the fact that it is traveling anywhere from 50 to 60 miles an hour or better—speeds at which a moving object has never been shot at before, and the chances of striking it would seem to be about zero minus. Yet Rear Admiral Evans is reported as stating that it would prove an easy mark for a 12-inch gun. The futility of making

Fig. 48. Illustrating Possible Use of Small Machine Guns Against Aeroplanes

such an attempt would be on a par with trying to shoot a fly with a sporting rifle at a hundred feet while the insect was flying faster than the marksman could follow its movements through the sights.

Operations in France. *Military Maneuvers.* On the other hand while few, who are in a position to know, entertain the idea that aeroplanes will ever supersede battleships, or put an end to war, they do know that they are destined to play an important part in the war game of the future, and most nations are now seriously developing this new auxiliary as an adjunct to their military establishments. What can be accomplished with the aid of this branch of the service designed to operate in the third dimension, is probably best illustrated by brief reports of the French maneuvers held in the fall of 1910 and that of 1911 and extending over a week in each year. Owing to the extraordinary progress of military aeronautics they were carried out on an unprecedented scale. Each opposing general had at his command well-organized detachments of dirigibles and aeroplanes with the necessary stations, repair shops, and a large and well-trained personnel. In 1910, fifteen air craft took part, four aeroplanes being assigned to each corps and three being assigned to the staff headquarters, together with four dirigibles, while the 1911 maneuvers were upon the most elaborate and impressive scale ever witnessed, the number of machines employed being greatly increased over the previous year.

Three aeroplane stations were established at different points some distance apart, while immense sheds were erected for the dirigibles Colonel Renard, Liberté, and Zodiac at the Camp Militaire, while another enormous "hangar" or loft was erected for the Clement-Bayard II at Issy-les-Moulineaux, the famous French aviation field. This shed was almost 400 feet long by 100 feet high by 70 feet wide and though merely a temporary structure cost 200,000 francs, or about $40,000. A building was also put up to manufacture hydrogen gas by a new secret process employing powdered ferro-silicon treated with caustic potash. The gas thus produced is said to be much purer than is possible with the usual commercial methods and proved very satisfactory in service.

The maneuvers began with a trip by the Clement-Bayard II of a little over two hours and at an average elevation of about 1,000 feet; during the entire time it was in wireless communication with the Eiffel Tower and the military headquarters. On the following day numerous flights were made for purposes of reconnoissance, the aviators making flights of some distance and reporting back in a very short time with the information gained, despite the heavy wind that prevailed. The results of observations made by the aerial scouts were such as to force the commanders to change their plans of battle twice. Notwithstanding a wind of 26 miles an hour that was frequently accompanied by rain, numerous flights were made the next day, Latham circling the entire series of the enemy's positions in a heavy rainstorm and promptly returning to report the information he had gained.

After this, the Clement-Bayard II made a reconnoissance of an hour's duration, landed, and immediately afterward started for Paris to place the two armies in communication. The flight was made at an average height of 1,200 feet and the distance of 75 miles was made with seven passengers in two hours and seventeen minutes. Constant communication was maintained by wireless with Paris (Eiffel Tower) and during the trip a number of carrier pigeons belonging to the various divisions were released. The smaller dirigibles, La Liberté and Colonel Renard, also made a number of trips. During the latter half of the week, the second part of *les grandes manœuvres* were carried out in the course of which numerous flights were made to carry dispatches distances as great as 50 miles for purposes of observation and the like. In each case, the aviator carried a military observer with him, usually an officer of engineers, and the information obtained subsequently proved to be startlingly accurate. Although four of the machines were disabled in service, their value as scouts and dispatch bearers could scarcely be underestimated.

On the next to the last day of the maneuvers, the weather improved and there was afforded the unprecedented sight of no less than four dirigibles and eight aeroplanes in the sky at once—an unequaled opportunity to test marksmanship with the new automobile-mounted, rapid-fire gun, had the use of the latter been possible. The Clement-Bayard II started in fine weather for the last trip of the maneuvers on the final day, but was almost destroyed by a storm before landing. The airship was caught by a violent wind and sent along at a speed greater than that of an express train passing below, while the lightning played so fiercely against the steel sides of the car and the wireless apparatus that it was feared that the hydrogen would be ignited.

The successful carrying out of military maneuvers on such an extended scale with the aid of airships and aeroplanes may be regarded as marking the advent of a new era in armaments. The French army has officially adopted the aeroplane as a "fourth arm" and as the result of the trials in question has decided to greatly increase its equipment. No less than twenty Farman biplanes and ten Bleriot racing monoplanes were ordered, which would bring the total to sixty machines in service. The new aeroplanes are designed to have a radius of action of 150 miles, lifting capacity sufficient to carry three men and 50 pounds of weight besides, and are to be equipped with a second or reserve motor. They are of the portable type as shown by Figs. 49 and 50. In addition, three military flying schools have been established and are to be augmented by four more. To

Fig. 49. Portable Type of Monoplane for Military Use

each of the new stations will be assigned twelve machines and twenty aviators. Stations are also to be established along the coast, those mentioned all being inland.

Military Aeroplane Tests. For the selection of more aeroplanes for this purpose, an open competition was held in the latter part of 1911. The general conditions to be fulfilled by the competing machines were as follows: To be built entirely in France of French materials; to be able to fly 186 miles in a closed circuit without a stop, and with a useful load of 660 pounds in addition to the fuel, oil, and water necessary for the trip; to carry three persons comfortably—the pilot, mechanic, and an observer; to have a mean speed of 36 miles per hour; to be capable of alighting without accident on stubble fields, plowed ground, sowed or clover land; and to be able to arise easily therefrom; also to be capable of easy transportation, whether dismantled or not, by road or rail, and to be easily and rapidly put together without minute adjustments.

Fig. 50. Portable Bleriot Mounted for Quick Transportation

After having satisfied a committee that it was entitled to enter the competition, each machine was put to a series of severe elimination tests, those passing the latter being entitled to enter the final test for classification. In the elimination tests, the machine was weighed and all parts stamped. Any part could be replaced during the tests by an exact duplicate, but no modifications were allowed, except in the case of propellers and wheels. It was necessary, however, to repeat the entire test from the beginning in case a part was replaced. Each maker was compelled to declare the amount of gas and oil required for the flight of 186 miles, and only this amount was provided. The first test was a cross-country flight carrying 660 pounds useful load, landing in a clover field between two flags 225 feet apart. Each machine was then required to arise from the same spot, circle, and re-alight on the same ground. It was then dismantled and returned to the starting point by road. The same test was then repeated, first by alighting upon and rising from stubble ground, and then from a plowed field, the machine being dismantled after each test and returned to the starting point by road as in the first test. This was followed by a speed trial, making a round trip of 36 miles, which was also a test of fuel and oil consumption. In case there was a shortage of less than 10 per cent, the test had to be repeated; where the shortage exceeded this, the machine was eliminated from the competition. In the altitude test, each aeroplane had to rise 1,875 feet in 15 minutes or less, carrying a load of 660 pounds. This test had to be successfully performed twice and concluded the preliminary trials. Out of an entry of thirty machines, only nine qualified—as follows: 1 Nieuport monoplane, 2 Deperdussin monoplanes, 2 Breguet biplanes, 1 H. Farman biplane, 1 Savary biplane, and 2 M. Farman biplanes.

The final trial, termed the "classification test," comprised a round-trip flight of 186 miles without alighting, and carrying a useful load of 660 pounds, the contestants being allowed three trials each. The machines were started five minutes apart in an order determined by drawing lots. The race was one of the most interesting in the history of aviation and was successfully completed by all but one of the nine machines. As a result, the remaining eight were classified as follows:

(1) Nieuport monoplane, 100-horse-power Gnome motor, average speed 70.2 m.p.h.

(2) Breguet biplane, 140-horse-power Gnome motor, average speed 57 m.p.h.

(3) Deperdussin monoplane, 100-horse-power Gnome motor, average speed 52.5 m.p.h.

(4) Breguet biplane, 100-horse-power Gnome motor, average speed 52 m p.h.

(5) H. Farman biplane 100-horse-power Gnome motor, average speed 50.6 m.p.h.

(6) M. Farman biplane, 70-horse-power Renault motor, average speed 45.6 m.p.h.

(7) M. Farman biplane, 70-horse-power Renault motor, average speed 43.3 m.p.h.

(8) Savary biplane, 70-horse-power Labor motor, average speed 40.2 m.p.h.

In accordance with the original program, the makers of the first machine were awarded a bonus of $20,000, an order for 10 machines at $8,000 each, and a bonus of $100 for each kilometer in excess of 60 made by the winning machine, this bonus amounting to $56,900, so that the Nieuport won $156,900; the Breguet $83,000, and the Deperdussin $59,500.

It will be noted that, throughout the maneuvers in question, no mention is made of bomb-dropping about which there has been so much talk, but which is not regarded so highly in military circles. Work of this kind is to be totally ignored in the curriculum of the schools in question. How small would be the damage done by aeroplane high explosive attack was shown by the Japanese bombardment of the Russian fleet in Port Arthur. The fire of the 11-inch siege guns, throwing a quarter-ton explosive shell, was directed by a skilled observer on a hill commanding the harbor, and the projectiles with their highly-explosive contents rained down upon the decks of the ships with the greatest accuracy, falling almost vertically. The entire Russian fleet was sunk, not by the shell fire, but actually by the Russians themselves, as subsequent examination revealed, which also showed that the damage done by the projectiles was astonishingly small. If, then, the falling of a 500-pound explosive shell from a height of two miles directly upon the deck of a ship, caused so little injury, the possibility of destroying a war vessel by means of small hand-launched bombs is practically nil. But for scouting, taking photographs, especially with the telephoto camera, and for sending information by wireless, the aeroplane is an arm whose importance can not be denied. Had such an aid been available in 1898, Admiral Sampson would have known within an hour that Cervera's fleet was resting quietly in Santiago harbor, instead of uselessly blockading the entrance to the harbor for a month, and the unfortunate Schley-Sampson controversy would never have occurred.

Aeroplane Maneuvers in United States. *Ely's Flight from the Birmingham.* That the aeroplane may be of as much assistance to the naval branch of the service as the army is already appreciated, as witnessed by Ely's attempted flight in a Curtiss biplane from the deck of the scout cruiser Birmingham to the Norfolk Navy Yard, some 30 miles from the place where he left the ship. This was undertaken in the latter part of November and, as the result of its successful outcome, attempts were made to rise from the deck of a war vessel and return to it. A wood platform 25 feet wide and 85 feet in length was built on the forecastle of the Birmingham to provide a run for the machine. This platform was given a downward slope and projected slightly beyond the bow of the cruiser, as will be noted in the illustrations of a later flight in San Francisco harbor. Ely's machine was assembled and tested at the Jamestown, Virginia, race track and then transferred to the war vessel by one of the government derrick lighters. Despite squalls of wind and rain, it was decided to attempt a flight and, starting his engine during a calm spell, Ely ran down the sloping platform at high speed and shot over the bow directly toward the water. As the biplane left the platform it settled rapidly till it struck the water with a splash, which was thought to terminate the experiment. Instead, however, the machine rose without difficulty to a height of about 150 feet and headed for shore, which was reached without any difficulty. Ely attributed his downward plunge to a faulty movement of the control wheel. When the machine struck the water, the propeller was damaged and the spray so clouded the aviator's goggles that it was only with difficulty he could see to make his way toward the land. Owing to the accident, a descent was made at Willoughby's Point, two and one-half miles distant, instead of continuing to Norfolk as originally planned. Examination showed that the damage to the propeller was slight and the flight could have been resumed, or an attempt made to return to the vessel, had this been desired.

The significant point of this performance is the fact that the aeroplane started under its own power from a vessel at rest with but an 85-foot run and a 30-foot drop. Considering the bad weather conditions, this was an excellent performance. A speedy cruiser offers the great advantage that she could be headed into the wind, or even where there was no wind, could steam fast enough to allow an aeroplane to rise from its deck without any preliminary run, while in alighting the aeroplane could simply hover above the vessel in motion and drop gently to her deck. In place of the cumbersome platform adopted for the experiment in question, all that would be needed would be troughs for the wheels to run in and these could be stowed away when not in use. For that matter, a special starting derrick, such as that originally employed by the Wright Brothers, could be used readily.

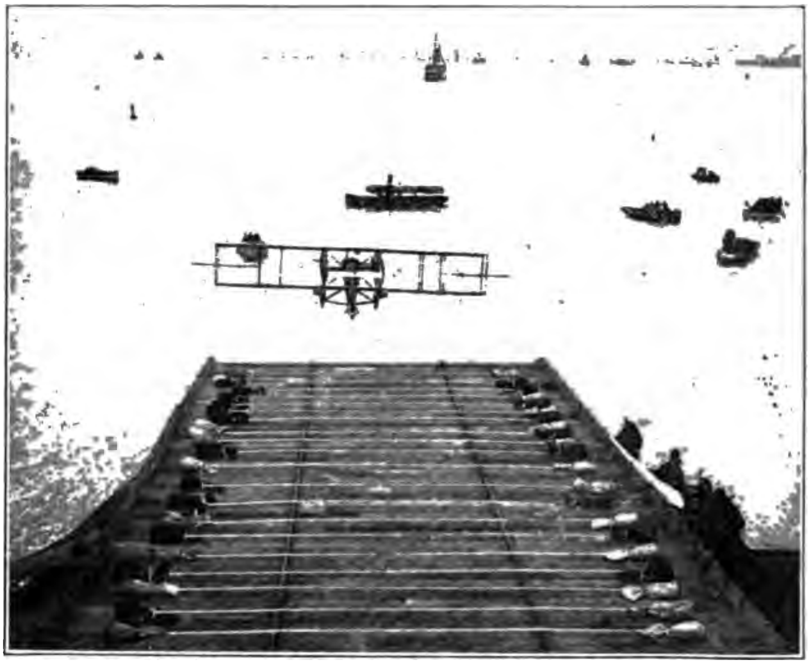

Fig. 51. Ely Making a Landing on the Deck of the U. S. S. Pennsylvania

The design of the aeroplane itself would also have to be modified to correspond to the conditions. The wheels would undoubtedly be necessary to make it possible to use the machine on land, but it should also be provided with hydroplane floats, similar to those employed on the Fabre marine aeroplane, to permit the machine to alight upon and again start from the surface of the ocean. The possibility of an aeroplane leaving and returning to a war vessel, such as the scout cruiser Birmingham, at will and with certainty should undoubtedly increase the usefulness of vessels of this type.

Ely received a prize of $500 for his flight from the United States Aeronautical Reserve, and a similar prize is offered for a flight of this kind from a merchant vessel. Two attempts to make the latter were undertaken at New York, the object being to return from a point 50 miles at sea with mail, but on each occasion a gale of wind made carrying out the experiment impossible. Curtiss himself was to have made the flight and even went so far as to have the starting platform built.

Ely in San Francisco Harbor. A few months later, January 17, 1911, Ely made a flight in a Curtiss biplane from the land and

Fig. 52. Ely's Machine on the Deck of the U. S. S. Pennsylvania

alighted easily on the deck of the U. S. S. Pennsylvania, anchored in the harbor of San Francisco, Figs. 51 and 52. This was preceded by a 12-mile flight from the aviation field where the start was made. A special platform 120 feet long by 40 feet wide had been erected on the after-deck of the vessel, canvas shields being placed at each side to prevent the machine going overboard in case it did not alight squarely on the platform. Ropes were stretched across the platform and made fast to bags of sand at either end to arrest the progress of the aeroplane, in case the skids with hooks provided especially for this purpose did not work as anticipated. Ely left the field, climbed 2,000 feet, crossed the San Bruno hills at a great height, and then descending, circled the shipping in the harbor. He headed straight for the Pennsylvania, shut off the motor while still at a considerable height, glided down to the platform and landed with perfect ease, the machine coming to a dead stop before running more than a third of the distance allowed. So little trouble was experienced in making the landing accurately that Ely was of the opinion that he could carry it out successfully in nine cases out of ten, given moderate weather conditions. Where the ship was under way and headed directly with the wind, it could undoubtedly be performed even in brisk weather. After a reception on board, Ely returned to the aviation field in sixteen minutes. As this was the second time he had started a flight from the deck of a naval vessel, he was more accustomed to the conditions and soared off with great ease.

Following these experimental flights, Curtiss perfected the hydroaeroplane and also devised a practical method of launching it from the ship on flexible wire cables, as described in the article on the "Hydroaeroplane." Curtiss also made flights to and from a cruiser in San Diego Harbor, the aeroplane and aviator being hoisted aboard after alighting on the surface alongside. The United States navy has acquired several of these machines and has inaugurated an aeronautical department, a number of the navy officers having become aviators at the Curtiss school.

Bomb-Dropping Performance. During the two days preceding Ely's flight, practical tests of the aeroplane for scouting and bomb-dropping were undertaken at the aviation field. Lieutenant Myron Crissey of the Coast Artillery dropped a special shrapnel bomb from a height of 550 feet while flying in a Wright machine piloted by Parmalee. The bomb consisted of a very thin shell of brittle white cast iron, loaded with black powder and bullets and fitted with a percussion cap. Its weight was about 8 pounds. Lieutenant Crissey succeeded in dropping it with considerable accuracy and it tore a large hole in the ground, scattering its contents round a radius of about 50 yards. This is the first time that an actual bomb was ever used in experiments of this nature and it is believed that it would be a comparatively simple matter to hit a battleship from a height as great as 3,000 feet, where the aeroplane itself would be safe from attack to a very great extent. For this purpose, however, it would appear to be more destructive to cavalry or infantry.

Scouting Operations. To ascertain the value of the aeroplane for scouting, flights were made by Lieutenant George Kelly of the 13th United States Infantry with Walter Brookins in a Wright biplane. He made sketches, drew maps, and took six photographs of the surrounding country, but failed to locate a body of troops that had left the Presidio Military Reservation a few hours before. This is the first time that an aeroplane had been utilized for military scouting purposes in this country, although employed to a considerable extent in this rôle abroad in military maneuvers, where the same inability to distinguish troops in the field has also been noted. Several errors in reporting the character of the different objects and landmarks seen were also noted, from which it is apparent that the aerial scout will require special training and experience in order to be of value to his commander, as some of the errors in question were of a nature that would have resulted disastrously had the information been acted upon in real warfare. This is not only the case when the country is viewed from the swift-flying aeroplane, but likewise applies to the dirigible, the two airships employed for scouting during the German army maneuvers, in the fall of 1910, having failed grievously.

Fig. 53. Real Scouting Service by Lieutenant Foulois in a Wright Biplane

One crew led its command into an ambuscade, while the other fell into the hands of the enemy through the failure of the motor.

In connection with the French military maneuvers, a special test was arranged to learn the effect that would be produced on a troop of cavalry by the sudden appearance of an aeroplane above it. For this purpose a Hanriot monoplane was flown immediately overhead and the horses were all but stampeded by the sight of the huge bird-like object and the noise of the motor. As the first encounter of the horses with a flying man almost put them to rout, regular drills have been held since to accustom them to the sight.

Actual War Scouting. The closest approach to scouting in actual warfare thus far carried out has been in connection with the rebellion in Mexico, in February, 1911. R. F. Collier loaned the War Department his new Wright biplane and Lieutenant Foulois was commissioned to fly it above the Mexican border during the hostilities, Fig. 53. There are 1,400 miles of border to be patrolled and the government called for volunteer aviators to perform this duty. In response, Charles K. Hamilton gave his services and, on February 10, he crossed the Rio Grande from El Paso, Texas, and reconnoitered at an altitude of 1,000 feet above Juarez, locating a body of Mexican troops.

Curtiss and His Hydroaeroplane. Another test simulating actual war conditions, were the flights of Glenn H. Curtiss in his hydroplane machine from the surface of the bay alongside the U. S. S. Pennsylvania. He made a short scouting trip and, on his return, alighted on the water alongside the cruiser as easily as if he were landing on shore. These trials were made shortly after the experimental tests of this machine mentioned in connection with a description of its construction. Their principal object was to demonstrate to the War Department that an aeroplane can be made an auxiliary of the modern man-of-war without the necessity of carrying cumbrous platforms on the ship itself in order to provide a starting and landing place. Instead, the aeroplane may be stowed on the superstructure and dropped into the water by one of the cranes in the same manner as the launches are handled, though the weight is naturally but a fraction of that of the latter. Its spread of wing does not involve any inconvenience, as even with the present construction the aeroplane may be readily dismantled and packed in small compass, the operation of reassembling it requiring only about an hour, while later designs made especially with naval service in view will undoubtedly render it possible to do much better. In fact, there appears to be no reason why a folding type of machine can not be evolved, making it possible to put it in commission for a flight at very short notice. The problem of launching has since been solved by allowing the aeroplane to slide down inclined cables as described in the article on the "Hydroaeroplane."

Italian Operations. To try out its aerial equipment, the Italian military authorities put one of its airships to a severe test. This was Dirigible No. 2, which was sent from Rome to Venice, a distance of 230 miles, crossing the Apennines above the Via Maggio Pass, which necessitated rising to an altitude of 6,500 feet and occasioned the loss of a large quantity of ballast and fuel. One stop was made for propeller repairs after having traveled 90 miles, and other stops were made in the two following days, requiring four days in all to make the trip, though the actual running time did not exceed twenty-four hours. The Italian army has also made considerable use of the aeroplane in its campaign against the Turks.

GUNS FOR AERIAL WARFARE

Coincident with the development of the dirigible and the aeroplane as a fourth arm to the military establishments of most civilized countries, serious efforts have been directed toward the evolution of an arm particularly adapted to bringing down these ships of the air. The great difficulty of hitting an airship makes the usual methods of warfare totally inadequate. The fire of infantry and even that of machine guns is of little use, despite their momentary mass effect, because of the limited range and effectiveness of the projectiles and the impossibility of observing their flight. Field and siege guns can not be elevated sufficiently and howitzers are deficient in range and rapidity of fire. All these classes of artillery are lacking in proper horizontal angular range and visibility of projectiles, their deficiencies having been proven by experiment.

Special guns are therefore required and no little attention is being given their design at the moment. Various types of such guns have already been developed by Ehrhardt, Krupp, Schneider, Skoda, Vickers-Maxim, and others abroad and in this country as well. The latter have been constructed in the American government arsenals, but so far there has been comparatively little interest in the subject here. Two guns of American make—one a 2-inch 30 caliber, and the other a 3-inch, both mounted on wheeled carriages, were tried without success against captive balloons, in 1909. One of these was the McClean-Lissack automatic rapid-fire gun, which was mounted on a 3-ton Packard truck, the tests being carried out at Cleveland, Ohio, under Lieutenant-Colonel O. W. Lissack of the Ordnance Department, U. S. A. The gun fired 3-pound shells at the rate of 100 per minute, the range being 3.5 miles, but as the ordinary shells were employed, their flight could not be followed by the eye. Shots were tried with the brakes of the car set and also released, there being no shock felt in the former instance, while only a slight movement due to the recoil was noticeable in the latter.

Because of its speed, weight, and strength, the automobile is particularly adapted not only for carrying light guns of this type, but also for providing a platform from which they can be fired with a reasonable degree of accuracy. Indeed the artillery motor car, armor-plated and carrying a gun bolted directly to its chassis, is the natural counterpart of the familiar armored train, and quite a number of armored and semi-armored automobiles carrying aerial guns have been developed abroad during the last year or two, Fig. 47.

Guns employed for attacking airships or flying machines must possess a maximum elevation of at least 70 degrees, a horizontal angular range of 360 degrees, and must further be capable of rapid handling. In Ehrhardt's 5-centimeter (2-inch) automobile gun, an attempt is made to satisfy these requirements by aiming the gun, which is supported at its center of gravity, with the aid of a shoulder rest to which the sights are attached. This method gives a maximum elevation of 70 degrees. The gun is mounted in an armored turret with a lateral range of 60 degrees to right and left, the turret itself forming part of a completely armored automobile. The same gun is also mounted on a semi-armored car, giving the gun a horizontal range round a complete circle.

For this purpose, Krupp has developed guns of 2.6-, 2.8-, 3-, and 4.2-inch caliber, with the trunnions close to the breech and having a maximum elevation of 75 degrees. As employed on automobiles, ships, and fortifications, the guns are mounted on carriages which rotate on pivots, while for field use a wheel carriage with a two-part axle, the halves of which are attached by hinge joints to the front of the long carriage, is employed. The rear end of the carriage is pivoted to a rail resting on the ground. If both wheels are brought in front of and locked beneath the gun, the latter can be revolved entirely round the pivot so as to point in any direction by turning the wheels by hand. Small changes of direction are obtained by means of an upper carriage which can be turned 5 degrees to the right or left. The durability of this construction has been proved by extensive trials.

The Schneider weapon is a 1.9-inch 60 caliber gun mounted in an armored turret carried on a completely armored automobile. The gun can be elevated 70 degrees, while the turret can be revolved round a complete circle. The Skoda is a 1.5-inch 70 caliber gun (caliber in this connection refers to the length of the gun) with a maximum elevation of 80 degrees. The Vickers firm, which, according to report, has brought out a 6-inch field howitzer suitable for use against airships, has also produced a 1.9-inch 3-pounder gun designed for use on fortifications, ships, and automobiles. A maximum elevation of 90 degrees is claimed for this gun, which, like Krupp's, has its trunnions near the breech and is elevated by a rack and pinion.

The aiming mechanism of a gun employed against airships must be such as to enable the gun pointer to follow every movement of the swiftly flying adversary. With Ehrhardt's gun, this is effected by sighting as with a rifle. Krupp employs two parallel connected telescopes, with verticals and reflecting eye pieces. One man aims the gun with the aid of one telescope; another, using the second telescope, elevates the gun and fires at the most favorable moment, without oral consultation with his partner. On steeply sloping land, the elevation required for a given range can not be obtained accurately from any published tables, so the telemeter is used instead. The necessary rapidity of fire is obtained with a self-closing breech, while great range and accuracy are secured by the employment of an unusually long gun and high muzzle velocities.

In airship warfare, the question of ammunition is particularly important. Shrapnel is not well suited to the purpose. With a large number of bullets and fragments the gas bag may be cut, allowing the gas to escape; but, while serious damage may thus be done to airships of the flexible and semi-rigid types in which the gas is confilled under considerable pressure in order to give stiffness. several of the separate gas bags of the rigid type might be pierced without bringing it down. Nor can complete success be reasonably expected by shrapnel connected by chains 8 to 10 inches long, as employed in the Italian experiments, or from shrapnel with rotating blades and fuses for the purpose of cutting the bag and igniting the gas. An additional difficulty in the employment of shrapnel is involved in determining the proper length of time at which to set the fuse, which does not agree with the tabular time of flight corresponding to either the measured distance of the object of attack or the distance deduced from the angle of fire. The setting of the time fuse, therefore, requires calculation, which is incompatible with rapid firing. The fuse also tends to burn very irregularly in the upper atmospheric strata of varying density which the projectile may have to traverse.

The most promising method of attack, therefore, is apparently to endeavor to strike the airship directly with shells and destroy it by their explosion and the scattering of their fragments. Ehrhardt has devised a shrapnel shell provided with a fuse for the ignition of the balloon gas. Krupp's shell has a contact exploder sensitive enough to be operated by impact on the envelope of the airship, which it penetrates before exploding in the interior. In the gun, this very sensitive exploder is prevented from going off by a mechanical device. A special slow-burning fuse reveals the course of the projectile through the air by its light at night and a heavy trail of smoke by day.

In this connection, it is appropriate to refer briefly to the method of firing. As the hostile airship is usually visible only for a short time and sometimes moves very swiftly, it can not be hit by direct aiming, even with the easily-observed fire shells. In order to utilize fully the few favorable moments, a number of shots are fired in rapid succession, varying slightly in direction and elevation but aimed in general accordance with the measured or estimated distance with proper allowance for the slope of the land, and corrections based on observations of the visible flight of the successive shots.

The diameters of the guns mentioned vary from 1.5 to 4.2 inches. But the effectiveness of such a small arm as the Skoda gun with its 1.5-inch diameter and firing a projectile weighing only 1.7-pounds is questionable, and the same remark applies to the 1.9-inch Schneider and Vickers-Maxim guns. The diameters most suitable for field work appear to be those between 2.4 and 3 inches, as they combine the requisite mobility of the gun with an effective explosive action, and also allow shrapnel to be employed. Although shrapnel appears to be ineffective against airships, as already pointed out, the possibility of employing it makes the gun useful for other field work. Krupp specifies a gun of 4.2-inch caliber for naval and fortification use.

In addition to these technical requirements, certain tactical qualities are also requisite. Guns employed for aerial warfare must possess great mobility in order that they may be rapidly transported from place to place in attacking scouts of the air. The automobile appears to meet every requirement. As it can be made strong enough for all military purposes, it allows the employment of a central pivot mounting especially well adapted for guns employed against airships; it can carry armor and can also transport the gunners and ammunition rapidly. An automobile thus armed, equipped, and protected by armor, is so heavy, however, that its speed can not greatly exceed 30 miles an hour, so that it would hardly be capable of pursuing airships traveling with a favorable wind which would bring their speed beyond its reach.

WIRELESS TELEGRAPHY IN AERONAUTICS

WIRELESS ON DIRIGIBLES

Early Experiments on Balloons. It will be apparent that one of the most valuable features of the use of the dirigible and the aeroplane in warfare is the possibility of communicating with headquarters by wireless telegraphy, which means the instant reception of information gained by scouting parties. Not long after the invention of sending messages through the air became a reality, Professor Slaby demonstrated that wireless signals emitted by a land station can be received by a balloon, floating freely in the air. The experiments were carried out in conjunction with the maneuvers of the Prussian balloon corps, and since then experiments have been made successfully in other countries. The balloon Condor, which made an ascension near Brussels in the latter part of 1909, maintained uninterrupted communication with the station on the Brussels Palais de Justice, and also caught signals sent from the Eiffel Tower at Paris, 180 miles distant. Prior to this, Professor Hergesell had already demonstrated the great value of the application of wireless telegraphy to balloons by controlling the valves of unmanned sounding balloons (small balloons sent aloft for the purpose of carrying meteorological instruments), at heights extending to ten miles, by wireless impulses. The receivers of the balloons were tuned to different wave lengths, so that the valve of any one balloon could be opened and that particular balloon brought down at will.

In a series of experiments made with the German military balloon Gross II, in the autumn of 1908, messages were successfully sent from, as well as to, the airship, the first balloon wireless stations being constructed according to the Telefunken system. It was proved by preliminary experiments in the balloon shed that the danger of igniting the contents of the gas bag by sparks emitted from the wireless apparatus could be averted by taking suitable precautions. This danger is least with airships of the flexible and semi-rigid types, in which the gas bag possesses very few metallic parts that could draw sparks from the highly charged aerial which is used for sending and receiving the flashes from the air. The suspension of the car of the Gross by hempen ropes insured the complete insulation of the electrical apparatus from the gas bag, and all parts at which sparks were formed were enclosed in gas-tight envelopes. For military reasons, the details of these experiments were not made public, but the results are said to have been very satisfactory.

These experiments have proved that electromagnetic waves are propagated to great heights in the atmosphere and that the part played by the earth in wireless telegraphy is far less important than has been assumed. Thus, one of the principal theoretical objections to the application of wireless to airships has been shown to be fallacious. In the German army maneuvers of 1909, the Gross II demonstrated, for the first time, the practical utility of wireless telegraphy on a scouting balloon. The Zeppelin airship which took part in the maneuvers did not possess this advantage. Subsequently, the Zeppelin III was equipped with wireless apparatus and it was shown that even with a rigid, metallic-framed airship of this type, wireless signals could be transmitted with safety to a distance of 300 miles or more. All of the later Zeppelin airships which have since been wrecked, particularly the passenger-carrying types, were equipped with wireless.

Dangers from Electric Discharge. While of inestimable advantage, the presence of the wireless apparatus on a metallic airship exposes it to new dangers, some of which are also present in the case of the aeroplane. The chief source of risk is the large volume of inflammable gas necessary for flotation in the case of the huge dirigibles. In a thunder storm, a balloon is subject to sudden variations of electric charge which may produce sparks capable of igniting its contents. Wireless signals are accompanied by equally great and rapid changes of potential which may produce the same result.

It seems probable that the destruction of the Zeppelin airship at Echterdingen was due to atmospheric electric discharges during a thunder storm, while the catastrophe which befell the French military dirigible La Republique in September, 1909, also appears to have been due indirectly to an electric spark. A hole was torn in the gas bag by the breaking of a propeller blade, which in itself would not have been sufficient to have caused the sudden drop of 300 feet. It is a well-known fact that gas or steam, escaping rapidly from an orifice, will acquire an electric charge which may produce powerful sparks, and it is thought that this took place immediately following the rupture of the gas bag of the Republique, setting its contents on fire.

As the gas can not be ignited by discharges from the envelope itself, the netting, ropes, and similar poor conductors (unless they become saturated with water), but can be easily set fire to by sparks from the metal parts of the valve and other masses of metal, it is obvious that all metal and other good conductors will have to be eliminated from the envelope. There seems to be no objection to the presence of metal in the car, while a well-conducting drag rope is a safeguard against explosion in landing. If all conductors are removed from the vicinity of the gas bag, there would appear to be no danger in the application of wireless telegraphy to airships of the flexible type. If the same precautions be taken, dirigibles of this class are no more liable to ignition by atmospheric electrical discharges than the free balloon.

In rigid airships with metallic frames, the conditions are totally different. It will be apparent in the Zeppelin type, with its aluminum frame and its numerous gas bags filled with hydrogen, every condition of easy ignition is present. Between the great cylindrical conducting frame, which is more than 400 feet long and 40 feet in diameter, and the surrounding air, there may exist a difference of potential of 65,000 volts when the airship is horizontal, and of 50,000 volts, when steeply inclined. A spark capable of causing ignition may be caused by a difference of potential of only 3,000 volts. As it does not appear to be practicable to substitute wood for the aluminum framing, Zehnder recommends protection of the airship by lightning rods projecting beyond the reach of escaping gas. He also suggests making the gas container of sheet metal, the stiffness of which might make it possible to employ a lighter skeleton, thus keeping the weight within the same limit as at present. No electrical discharge could take place within this metallic envelope and the induced surface charge would escape harmlessly into the atmosphere from projecting seams and points. As an additional precaution, the aluminum cars could be connected with the aluminum balloon at several points by a number of wires, so that the aeronauts would be enclosed in a sort of Faraday's cage, protecting them from external electrical influences.

Preventive Methods. The experiments of Professor Wiener have not only served to demonstrate the value of a wire cage as protection against electrical discharges, but likewise have illustrated what happened to a balloon when struck by a spark. For this purpose, a model balloon was suspended above a large induction coil with the gaps of the secondary so arranged that the largest diameter of the balloon was between one pair, while a second pair was located to discharge immediately below the valve opening of the balloon. When a spark was passed completely through a collodion balloon, filled with either hydrogen or illuminating gas, the gas ignited without explosion so that the balloon was quietly consumed. It is only when the balloon contains air mixed with gas that explosion takes place. A balloon can even be traversed by sparks without being ignited. Metzeler has recently introduced a balloon material composed largely of aluminum for the purpose of protecting the gas from the sun's rays, but experiments prove that this material is no better conductor than the ordinary balloon fabric. Sparks can be passed through a balloon of Metzeler's material without causing ignition and even collodion balloons can transmit a few sparks without burning. If the flow of sparks be so rapid and dense as to resemble a flaming arc, it may directly ignite the fabric. Even if it were possible to make a balloon of conducting material, it would still be desirable to surround it with a wire cage, as lightning naturally follows the shortest path. With this provision, the conductivity of the balloon is of no importance. Owing to its greater strength the wire netting need not be heavier than the hemp netting ordinarily employed on dirigibles of the flexible and semi-flexible types. All the experiments just referred to were made with unprotected balloons, but a model surrounded by a wire cage allowed ordinary sparks to pass indefinitely, while it also withstood a flaming arc for a short time, without igniting—fifteen seconds direct contact with the flame was necessary to produce ignition. The ropes supporting the car must also be of wire and must completely surround the car. It might be supposed that making the outside of the balloon a good conductor would rather invite danger from lightning, but this is not the case. Although the ordinary balloon envelope is a fairly good insulator against low voltages, it is unable to resist the high tension of atmospheric electricity. An electroscope charged to 2,000 volts is discharged in less than a second, when it is touched with a roll of balloon fabric about six inches long. Hence, the balloon increases the electrical tension immediately above and below it, as much as it would do if it were a perfect conductor, but when the discharge occurs, its destructive action will be greater in proportion to the electrical resistance opposed to it. It might also be objected that the Faraday's cage would prove a source of danger to the occupants. The discharge, however, passes chiefly through the wires, and only partial or inductive discharges can strike those in the balloon. It is evident that the Faraday's cage is quite as readily applicable to the aeroplane as it is to the dirigible, though its use might complicate the employment of the aerial for wireless telegraphy, as referred to later.

On the other hand, it is quite possible that the surrounding network of wire might be employed for both purposes by suitably protecting the instruments. But even when a balloon is thus protected from lightning, it is exposed to another danger, atmospheric electricity. A balloon has been ignited and consumed by small sparks produced by touching the escape valve after landing. This valve and the filling tube, normally open during flight, are the two places in which the gas can come into contact with the air and therefore need special protection. The simple and long-known device employed in the Davy safety miner's lamp can well be employed for this purpose. These safety lamps are designed to protect miners from explosions of fire damp, the flame being surrounded by a fine wire netting which conducts heat so well that the temperature required to ignite the gas can not be produced on the outside. Any gas which enters the lamp burns quietly without producing an explosion. Both the escape valve and filling tube of the balloon could be surrounded with a fine netting of copper wire, which would also afford protection from lightning in certain cases.

An electric discharge may be precipitated by pulling the valve cord in a strong electric field, as, according to Paschen's experiments, the gap that a certain tension will bridge is greater in hydrogen than in air. This is shown by connecting a Bunsen burner with one pipe of an induction coil and gradually raising the other above it until the opening is too great for the sparks to bridge. Upon turning on the gas, the flow of sparks will recommence. If the burner be surrounded with a wire netting, the gas will burn only on the outside. The experiments with the model balloons and a large induction coil showed that when the sparks passed beneath the open filling tube of the balloon, ignition sometimes followed, but where protected by a wire netting, a flaming arc playing upon the netting for a minute did not light the gas.

Wireless on the Zeppelins. In regard to the employment of wireless telegraphy on the Zeppelin type of the present form—an arrangement of the aerial which would minimize the danger of ignition and would also furnish the best electrical conditions for the transmission of signals is suggested; as the hull of the Zeppelin is traversed by a vertical shaft or well, it is possible to support the aerial by a simple Eddy kite, which would be kept aloft by the motion of the airship. The wireless apparatus, including the dynamo, would be housed in the middle of the runway which connects the two cars. The kite would be connected with the apparatus by a wire from 600 to 1,200 feet in length, *i.e.*, one-fourth to one-fifth the length of the electric waves employed. A second wire of the same length and carrying a weight at its end would hang downward from the apparatus and would be kept as nearly vertical as possible by insulated stay or guy lines attached to the cars. The lower wire might, however, be replaced by a fan-shaped antenna about 200 feet long, attached to the frame of the airship and projecting about 30 feet below the hull. With this arrangement communication would be possible even when the ship was flying low. Fouling of the propellers would have to be guarded against by enclosing them in wire baskets or housings.

The **T**-shaped antenna which is carried by ships using the Telefunken system, could also be applied without difficulty to the Zeppelin airship, as the metal frame is abundantly able to carry a light, hollow mast about 30 feet high, which could be raised and lowered by ropes. The stability of the airship, however, would be affected more by this complicated device than by the kite. Experiments have shown conclusively the great promise of the use of wireless telegraphy on airships, but an indispensable prerequisite to its adoption would appear to be the electro-technical development of means of protection from all danger of injury through the working of the apparatus itself, or from atmospheric electricity.

WIRELESS ON AEROPLANES

Owing to its far greater speed and radius of action as well as its more general availability, the employment of wireless telegraphy on the aeroplane holds far more promise for military use. With experience in taking observations from a height, it will become possible to plot maps, note the character of emplacements, and the position of troops from an altitude that would make danger from shell fire from below out of the question. To be of any value, the dirigible must be so large as to make this impossible.

First Message. To James McCurdy, one of the Curtiss school aviators, belongs the distinction of having been the first to communicate by wireless from an aeroplane to a land station. This was on August 27, 1910, when he sent the following message from a Curtiss biplane:

> Over Barren Island, N. Y., 6:45 P. M., Aug. 27, '10.
>
> To H. M. Horton:
>
> Another chapter in aerial achievement is recorded in the sending of this wireless message from an aeroplane in flight. McCURDY.

Horton was the wireless operator on the roof of the Sheepshead Bay race-track grand stand, two or three miles distant from Barren Island, though the distance was probably less in an airline. The apparatus was an ingenious makeshift merely intended for the purpose of sending and was not capable of receiving a message. It was extremely compact, the complete outfit, with the exception of the battery, being attached to the steering wheel of the aeroplane. The battery was carried in the aviator's vest pocket, while the aerial consisted of 50 feet of ordinary wire held straight by a small lead weight, the whole trailing after the machine in flight. Such an outfit naturally had but a very limited range, probably not more than five miles, owing to the small amount of energy available, and would be subject to destructive interference from the waves sent out by more powerful stations in its vicinity. It was intended only to demonstrate the possibility of communicating with an aeroplane in flight.

Owing to the high speed at which an aeronautic motor runs, however, it would be practical to carry a very compact alternating generator which would weigh very little and still give the aeroplane sending station a comparatively wide radius of action—doubtless up to 100 miles or more, due to the greater facility with which the electromagnetic waves can be transmitted from a height. The remainder of the apparatus could likewise be made in very compact and durable form, so that there would appear to be no "wireless problem" where the aeroplane is concerned—it is merely a matter of designing instruments for the purpose.

Horton's Experiments. The question of equipping the aeroplane with a suitable aerial that would be effective without being an encumbrance, as well as the fact that a very substantial percentage of the energy emitted by the sending apparatus was absorbed by the numerous guy wires which also acted as a shield to the antennas, appeared to present a difficult obstacle at first. Both, however, have been overcome by a very simple expedient, that of employing the guy wires themselves as the antennas. After experimenting for a long while with numerous different methods of stringing separate antennas, H. M. Horton hit upon the idea of using the wires for this purpose, while the motor is utilized as a ground. Experiments which were made with a machine thus equipped and located in the building of the United States Aeronautical Reserve in New York City proved most successful. Messages were received from various stations throughout the city and even from ships at sea, despite the fact that the aeroplane was located on the first floor of the building and was not connected with any form of antenna protruding above the roof. A very light equipment was used, the total weight not exceeding 65 pounds, although a 6-inch spark coil was employed. Energy was derived from a 12-volt storage battery with a 50-ampere-hour capacity, the six cells weighing but 40 pounds. The guy wires were connected in series and gave a total length of 800 feet on the machine in question. However, the employment of a storage battery in this connection can be considered only as a temporary expedient in view of the obvious limitations of such a source of energy.

Fig. 54. Parmalee and Lieutenant Beck in a Wright Biplane, Operating a Wireless Outfit

For extended practical use, a generator would be necessary. As the required power is right at hand, this could take the form of a small high-frequency alternator, and as this could be wound for a high voltage, the weight of the transformer necessary could be correspondingly reduced.

Recent Records. *Lorraine.* Numerous other experimenters have been at work with wireless during the past year or so, Robert Lorraine, in England, having succeeded in maintaining perfect communication from his aeroplane with a land station more than a mile distant.

Beck. The most practical results, however, were those of the trials carried out during the course of the aviation meet at San Francisco in January, 1911. Lieutenant Paul W. Beck of the United States Signal Corps went aloft in a Wright biplane piloted by Parmalee, Fig. 54, and transmitted wireless messages for a considerable distance while at a height of 1,000 feet. These messages were received at the Mare Island Navy Yard, 40 miles away, as well as at the Yerba Buena Island training school in San Francisco Bay. In Lieutenant Beck's experiments a 100-foot length of copper wire was trailed along behind the aeroplane. In France, wireless messages have been successfully transmitted 15 miles from an aeroplane; while in England, during a trip of the military dirigible Beta, communication was established with headquarters 30 miles distant.

McCurdy. During the Bridgeport, Connecticut, Aviation Meet in May, 1911, McCurdy set a new long-distance mark in wireless communication from an aeroplane by sending messages to the operator in the dome of the World Building in New York City, 55 miles distant, while a number of other stations within a shorter radius also picked up his messages. The apparatus was constructed for the *New York World* in three days by Oscar Roesen, an electrical engineering student at Stevens, and was probably the first set capable of both sending and receiving that has been mounted on an aeroplane. The transmitter consisted of a 4-inch induction coil of the ordinary vibrating type, supplied with current by 15 dry cells connected in series, thus giving a voltage of 22.5, while the amperage was high. The helix was a wood frame 5 inches in diameter and wound with 12 turns of No. 6 B & S gauge aluminum wire, while the condenser consisted of copper plates with a special insulating material as the dielectric. An ordinary telegraph key was employed. The receiver comprised a mineral detector, two straight tuning coils, and a pair of 2,000-ohm head phones. The aerial consisted of a series of wire strung forward from the tail on either side to points directly above the ailerons at the ends of the upper plane of the Curtiss machine, Fig. 55. For a ground, or rather for a balancing aerial, the motor supplemented by wires carried out in either direction to the ends of the main plane was employed. The apparatus proper was mounted in a small box carried below the aviator on the skids of the machine, while the sending key was placed on the steering wheel. The arrangement is plainly illustrated by the accompanying sketch, Fig. 56. *A* is the box, *B* the key, dotted lines *C* the ground or balancing aerial, and full lines *CC* the aerial proper, the smaller sketch below showing how this was wired up. The weight of the complete outfit was between 40 and 50 pounds. Lieutenant Fickel, U. S. A., detailed by the War Department to attend the meet, was very much impressed with the set and sent a complete description of it to the Signal Corps at Washington. Experiments were first made on a Saturday and while McCurdy's signals were plainly heard at the temporary receiving station on the field, the

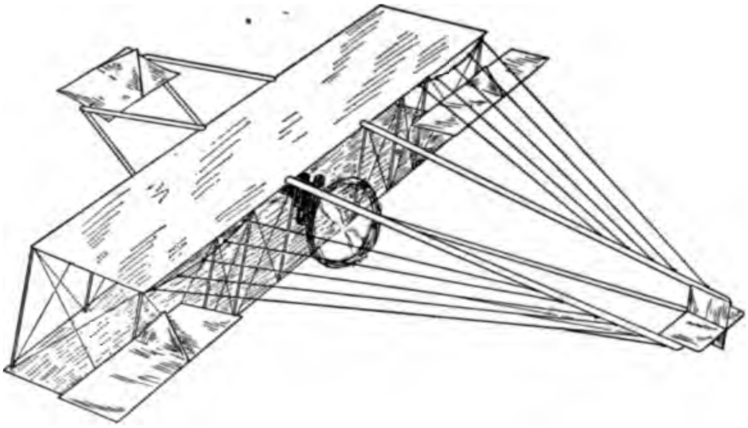

Fig. 55. Diagram Showing Method of Making an Aerial on a Biplane

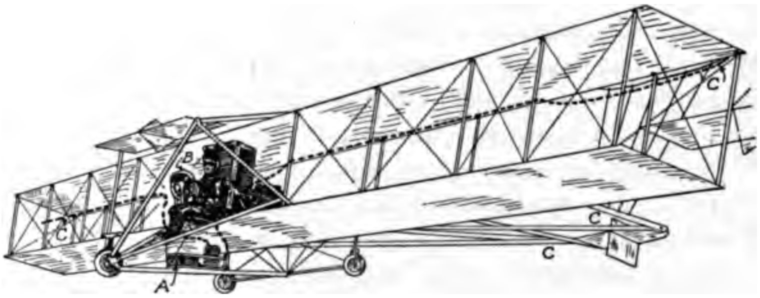

Fig. 56. Diagram Showing Location of Circuits and Equipment of a Wireless Outfit

interference of numerous adjacent stations made it impossible for the operator in New York to pick them up. On the following day there was an absence of interference, and the messages were plainly heard in New York on three different trials, thus establishing a new distance record for aeroplane work, and this is of even greater importance in having reached the heart of the metropolis, as New York City is generally conceded to have many adverse elements for successful wireless reception from outside points, chiefly due to the great number of high, steel-frame buildings. Tests made of the receiving abilities of the set showed it to be capable of picking up messages from a distance of 200 miles, but unfortunately no trials of this nature were carried out in the air.

General Problems. It will be apparent from the foregoing that all of the experiments made thus far have been in transmitting messages from an aeroplane in flight, and while this is a very valuable accomplishment, receiving is quite as necessary, to take complete advantage of the value of the wireless as a means of communication, and for reasons that are obvious this does present more of a problem than the mere sending of messages.

Eliminating Noise. The chief difficulty is that of noise, as with the unmuffled motors now generally in use, it is practically impossible for two men sitting side by side in an aeroplane to carry on a conversation. This is further complicated by the rush of the wind and the high pitched note occasioned by the vibration of the numerous guy wires and struts, but with close-fitting, double-head receivers, there should be no difficulty in shutting out practically everything but the noise of the motor. The matter of expediency that has been responsible for the adoption of so many of the makeshift features of design that characterize the present-day aeroplane, and probably will continue at least for a few years to come, has likewise been responsible for the elimination of the muffler on the motor. But even now, design and construction have advanced to a point where there is really no necessity for longer doing without this essential, as both the muffler and its connecting pipe can readily be made of aluminum, though, for that matter, the weight of the standard type as employed on the automobile would not form any very serious drawback. Considerably more difficulty would be encountered in muffling motors of the rotary type, but they need it least, as the explosions of a seven- or fourteen-cylinder Gnome motor running at full speed overlap to a degree that converts the exhaust into a loud buzz, rather than the disagreeable and ear-cracking rapid-fire bang of the four- or six-cylinder vertical motor.

Use of Visible Signals. Should the usual audible method of receiving not prove practical, two alternatives are open, both involving the use of a visible signal. In one, a coherer could be connected with a tuning condenser shunted across it, the former being automatically decohered every two seconds by a striker actuated by a magnet excited by a clockwork contact maker. A relay and battery are connected in series with the coherer, and the local circuit of the relay is connected with another battery and small incandescent lamp. Each time a signal is received the lamp would light—one second for a dot and two seconds for a dash. These long signals are obviously necessary, but in spite of that a message could be received with reasonable rapidity. The second alternative is that of employing an inker, this method also involving the use of a coherer. The inking apparatus, however, is not only comparatively heavy, but in order to work satisfactorily, requires fairly close adjustment, so that it would not be suitable for use where there is much vibration—the question of vibration is probably the most serious element of the problem. The coherer is not a particularly sensitive receiver of the weak impulses which have to be caught, and has long since been practically abandoned in wireless practice. But even if it were sufficiently sensitive for such use, it would probably be impossible to make the coherer work long enough to start the local side of the relay working effectively, particularly if the mechanical decohesion had to be rapid. In fact, the actual number of impulses per second of a four-cylinder, two-cycle engine, or a six-cylinder, four-cycle, or any of the rotary motors, is too great to permit a coherer to act, while a coherer insensitive to the abruptness of the shock would not be sensitive enough to respond to the wireless impulses. Either the mineral or the electrolytic type of detector is far more sensitive, but as its adjustment must be delicate to work effectively, it would also be placed at a serious disadvantage by the vibration.

Forms of Aerial. The question of the most practical form of aerial to employ is another difficulty that affects both sending and receiving. The use of a long trailing wire, as well as the employment of the network of guys and braces, has already been referred to in connection with experiments carried out by McCurdy and American army officers. Trailing wires present so many sources of danger to a machine traveling at high speed, that few pilots would care to consent to their use, while connecting up the bracing of the aeroplane is equally impracticable as every piece of metal on the machine then becomes charged, and in sending, serious shocks might be received by the pilot or his passenger. Farman has employed two trailing wires, each about 400 feet long, and Baker has adapted a similar arrangement to a Bristol biplane in England, the wires, however, not being allowed to hang loose in the latter case, thus limiting their capacity. Instead of using balanced aerials, as in the McCurdy experiments described above, he coupled them to each end of an inductance coil, thus increasing their effective length to the greatest extent possible without sacrificing their efficiency. The apparatus consisted of a 6-inch induction coil with a ⅝-inch spark gap located as far away from the gasoline tank as possible. Two light brass rods extended from the coil well into the space between the two main planes of the machine and to one side of the tank, and two ⅜-inch rods sliding on these and with their ends separated by ⅝ inch, formed the spark gap terminals. Shunted across the spark gap was a condenser of the Leyden jar type, and an inductance coil consisting of seven turns of No. 14 copper wire wound on a light ebonite drum. This inductance had sliding contacts so that the number of turns used could be varied in the usual manner, in order to tune the two circuits. The two aerial wires were connected to the two ends of the inductance in use and the aerial circuit was brought into tune with the shunt circuit. A storage battery of five cells supplied the necessary energy, about 50 to 60 watts being required. Two new arrangements which should greatly increase the efficiency of the apparatus have since been adopted. The more important of these is a long, light brass tube attached to the tail of the aeroplane but insulated from it. This acts as counter-capacity or "ground" to a long aerial wire on the other side. This aerial starts from the nose of the machine, and is carried thence to the extreme outer edge of the main plane, back to the tail, and from this to a loose connection, 60 feet of copper wire trailing behind.

Possible Developments. It is evident that these isolated experiments, while more or less numerous, are but the beginning of the serious study that will be given the matter within the next year or so. Nine-hour, non-stop flights covering more than 400 miles give some idea of what will be accomplished in the way of long-distance flying in the near future—in fact, they make the possibility of being able to cover more than 1,000 miles per day of twenty-four hours seem very close at hand, so that Atwood's proposal to fly across the Atlantic in three days appears to be only a question of carrying sufficient fuel. To be able to keep in constant communication with these long-distance flyers would be invaluable, and that is what experimenters in the wireless field aim to accomplish.

Wireless telegraphy from the dirigible has already reached a more advanced stage, as neither the use of a trailing wire nor the matter of weight present such serious disadvantages as on the aeroplane. The apparatus used on the British military dirigible Beta weighed approximately 100 pounds, and as signals have been sent 50 miles under favorable conditions, the proportion of weight to distance of transmission was, roughly speaking, 2 pounds. But an ordinary induction coil and accumulator were employed, so that this can scarcely be taken as a criterion. They were used in connection with a trailing aerial and a counter-capacity, and, as the chief requirement of the latter is superficial area to take the charge, as light a substance as possible, such as paper-thin sheet aluminum, could be employed.

The form of the wireless installation suggested by one of the chief English experimenters as best adapted to the needs of the airship is that of a small auxiliary motor, say, a two-cylinder, 3- to 4-horse-power machine, directly coupled to an alternating generator of about 2 kilowatts capacity, together with an aerial about 350 feet long, and a counter-capacity in the form of very thin metallic sheeting, suitably disposed. Considerable attention is now being given to the production of portable apparatus. The chief limiting factor in connection with small receivers naturally has to do with the detector, the vacuum valve type of Professor J. A. Fleming probably being the most suitable in many respects, and next to that an electrolytic detector.

Akron Outfit. The new dirigible Akron, in which Melvin Vaniman is to make his second attempt at crossing the Atlantic, is a forcible example of the careful attention now being given to wireless equipment and the dependence placed upon it as a safeguard. Vaniman, it will be recalled, was Wellman's chief engineer on the America, and he has taken advantage of that experience to embody all the improvements in the new equipment that were found lacking in the America's set. The latter had a sending range of only 80 to 90 miles, so that while the operator could catch the numerous inquiries that filled the air regarding the America's whereabouts during the 48 hours or more that it was out of sending range, he could not reply to any of them. The equipment of the Akron is a Marconi set with a sending range of 700 to 800 miles and consists of a 3-kilowatt, 120-cycle, alternating-current generator, direct driven by a 17-horse-power, 4-cylinder gasoline engine. For receiving, the most advanced type of musical, rotary spark gap and a valve detector will be employed. As a counter-capacity does not permit of the most efficient operation, a flexible, phosphor bronze wire trailing in the water will constitute the ground, the equilibrator which was used for that purpose on the America having been abandoned. This trailing ground is wound on a drum and sufficient wire is provided to reach the water at any point from 100 to 1,200 feet elevation, the amount played out depending upon the height at which the airship is flying. However, should the airship rise higher, provision has been made to operate the equipment as an unbalanced Hertz oscillator without a ground. The transmitter is of the loose-coupled type and is so arranged that considerable variation in the natural period of the open oscillating circuit will have a minimum effect upon the transmitted signals. The frame of the envelope is used as one side of the oscillator, the trailing ground acting as the other. Particular care has been taken in the design of the various parts of the apparatus to prevent any possibility of a spark from the high-tension apparatus igniting the hydrogen gas. Jack Irwin, whose call of distress from the America brought the S. S. Trent to their rescue, will accompany the Akron as operator.

AIRSHIP CROSSING ONE OF THE NATIONAL ROADS IN RURAL FRANCE

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BUILDING AND FLYING AN AEROPLANE

PART I

One of the commonest phases of interest in aviation is the desire to build a flying machine. In fact, this is very frequently the first thing the experimenter undertakes after having gone into the theory of flight to some extent. Only too often, no effort whatever is made to get beyond theory and the machine is an experiment in every sense of the word. An experience of this nature is costly —far more so than is agreeable for the student, and is likely to result in disgusting him with aviation generally. There are hundreds of schemes and principles in the art that have been tried again and again with the same dismal failure in the end. Refer to the story of the Wright Brothers and note how many things they mention having tried and rejected as worse than useless. About once in so often someone "rediscovers" some of these things and, having no facilities for properly investigating what patent attorneys term the "prior art" (everything that has gone before, from the beginning of invention, or at least patented invention) becomes possessed of the idea that he has hit upon something entirely novel and wholly original. There is no desire in the present work to discourage the seeker after new principles—undoubtedly there are many yet to be discovered. The art of flight is in its infancy and there is still a great deal to be learned about it, but there is no more discouraged inventor than he who discovers a principle and, after having experimented with it at great expense, finds that it is only one of many things that numerous others have spent considerable money in proving fallacious, a great many years ago.

If it be your ambition to build a flying machine and you believe that you have discovered something new of value, it will be to your interest to retain a responsible patent attorney to advise you as to the prior art, before expending any money on its construction. You will find it very much more economical in the end. There are probably not more than half a dozen men alive in this country today who "know all the schemes that won't work." The average seeker after knowledge is assuredly not likely to be one of these few, so that until he knows he is working along new and untried lines that give promise of success, it will pay him to stick to those that have proved successful in actual practice. In other words, to confine his efforts in the building line to a machine that experience has demonstrated will fly if properly constructed and, what is of equal importance, skilfully handled. Build a machine, by all means, if you have the opportunity. It represents the best possible experience. But as is pointed out under the "Art of Flying," take a few lessons from some one who knows how to fly, before risking your neck in what is to you a totally untried element. Even properly designed and constructed machines are not always ready to fly. An aeroplane needs careful inspection of every part and adjustment before it is safe to take to the air in it, and to be of any value this looking-over must be carried out by an experienced eye.

BUILDING AEROPLANE MODELS

The student may enter upon the business of building to any extent that his inclination or his financial resources or his desire to experiment may lead him. The simplest stage, of course, is that of model building and there is a great deal to be learned from the construction and flying of experimental models. This has become quite a popular pastime in the public schools and some very creditable examples of work have been turned out. The apparent limitations of these rubber-band driven models need not discourage the student, as some of the school-boy builders have succeeded in constructing models capable of flying a quarter mile in still air and their action in the air is wonderfully like the full-sized machines.

Models with Rubber-Band Motor. The limitations of the available power at command must be borne in mind, as the rubber-band motor is at best but a poor power plant. It is accordingly not good practice to have the spread of the main planes exceed 24 inches, though larger successful models have been built. In attempting to reproduce any of the well-known models, difficulty is often experienced in accommodating the rubber-band motor to them, as even where the necessary space is available, its weight throws the balance out entirely, and the result is a model that will not fly. This has led to the production of many original creations, but these, while excellent flyers, would not serve as models for larger machines, as of necessity they have been designed around their power plants. The rubber bands for this purpose may be purchased of any aeronautic supply house. The most practical method of mounting the motor is to attach it to the rear end of the fuselage, usually a single stick, which is accordingly made extra long for that purpose. At the other end it is attached to a bent wire fastened to the propeller in order to revolve the latter. An easy way to wind up the motor is to employ an ordinary egg beater, modified as described below, or a hand drill, inserting a small wire yoke in the jaws in place of the usual drill, or bit. This yoke is placed so as to engage the propeller blades, and the latter is then turned in the opposite direction, storing energy in the rubber band by twisting its strands tightly.

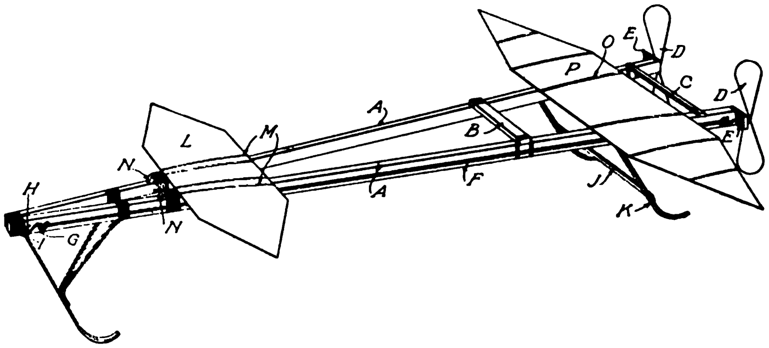

Fig. 1. Details of Main Frame of Rubber-Band Driven Aeroplane Model

For those students who do not care to undertake an original design at the outset, or who would prefer to have the experience gained by building from a plan that has already been tried, before attempting to originate, the following description of a successful model is given. This model can not only be made for less than the models sold at three to five dollars, but is a much more efficient flyer, having frequently flown 700 feet.

Main Frame. The main frame of the model monoplane consists of two strips *A* of spruce, each 28 inches long, and measuring in cross section ¼ by ⅜ of an inch. As shown in Fig. 1, the two strips are tied together at the front with strong thread and are then glued, the glue being spread over and between the windings of the thread, Figs. 1 and 2. The rear ends of these strips are spread apart $4\frac{1}{4}$ inches to form a stout triangular frame, and are tied together by cross bars of bamboo *B* and *C* which are secured to the main strips *A* by strong thread and glue.

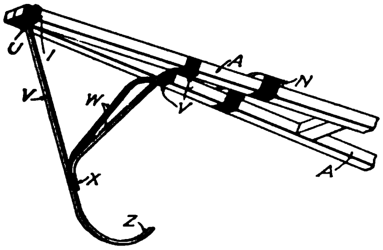

Fig. 2. Details of Forward Skids of Aeroplane Model

Propellers. The propellers *D* are two in number and are carried by the two long strips *A*. Each propeller is 5 inches in diameter, and is whittled out of a single block of white pine. The propellers have a pitch of about 10 inches. After the whittling is done they are sandpapered and coated with varnish. The thickness of the wood at the hub E_2, Fig. 3, of the propeller should be about $\frac{5}{8}$ inch. At the rear ends of the strips *A*, bearing blocks E_1 are secured. These bearing blocks are simply small pieces of wood projecting about $\frac{5}{8}$ inch laterally from the strips *A*. They are drilled to receive a small metal tube T_2 (steel, brass, or copper), through which tube the propeller shaft T_1 passes.

The propeller shaft itself consists of a piece of steel wire passing through the propeller hub and bent over the wood, so that it can not turn independently of the propeller. Any other expedient for causing the propeller to turn with the shaft may obviously be employed. Small metal washers T_3, at least three in number, are slipped over the propeller shaft so as to lie between the propeller and the bearing block.

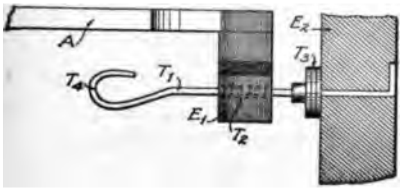

Fig. 3. Details of Propeller and Rudder of Aeroplane Model

That portion of the propeller shaft which projects forwardly through the bearing block E_1 is bent to form a hook T_4. To the hook T_1 rubber strips *T*, by which the propellers are driven, are secured. The rubber strips are nearly as long as the main strips *A*. At their forward ends they are secured to a fastening consisting of a double hook *GH*, the hook *G* lying in a horizontal plane, the hook *H* in a vertical plane. The hook *G* holds the rubber strips, as shown in Figs. 1 and 4, while the hook *H* engages a hook *T*. This hook is easily made by passing a strip of steel wire through the meeting ends of the main strips *A*, the portions projecting from each side of the strips being bent into the hooks *I*.

Skids. Three skids are provided, on which the model slides, one at the forward end, and two near the rear end. All are made of bamboo. As shown in Fig. 2 the front skid may be of any length that seems desirable. A 6-inch piece of bamboo will probably answer most requirements. This piece *N* is bent in opposite directions at the ends to form arms *Z* and *U*. The arm *Z* is secured to the forward ends of the two strips *A*, constituting the main frame, by means of thread and glue. The strips and skid are not held together by the same thread, but the skid is attached to the two strips after they have been wound. Hence, there are two sets of windings of thread, one for the two strips *A* themselves, and another for the skid and the strips. Strong thread and glue should be used, as before. In order to stiffen the skid, two bamboo struts *W* will be found necessary. These are bent over at the ends to form arms V_1, Fig. 2. Each of the arms is secured to the under side of a strip *A* by strong thread and glue. The arms *X* are superimposed and tied to the bamboo skid *V* with strong thread and glue.

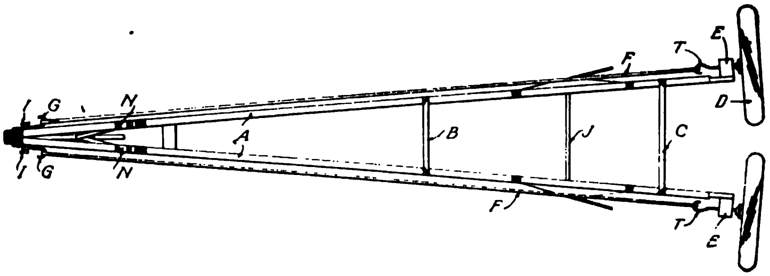

Fig. 4. Details of Rear Skids on Aeroplane Model

The two rear skids, of which one is shown in Fig. 5, consist each of two 5-inch strips of bamboo *S*, likewise bent at either end in opposite directions to form arms S_2 and S_3. The arms S_2 are fastened to the strips *A* by strong thread and glue. To stiffen the skids a strut C_1 is provided for each skid. Each strut consists of a 3-inch strip of bamboo bent over so as to form arms C_2. Strong thread and glue are employed to fasten each strut in position on the strip and the skid. In the crotch of the triangular space B_1, a tie bar J, Figs. 4 and 5, is secured by means of thread and glue. This tie bar connects the two skids, as shown in Figs. 1 and 4, and serves to stiffen them. The triangular space B_1 is covered with paper, preferably bamboo paper. If bamboo paper is not available, parchment or stiff light paper of some kind may be used. It does not need to be waterproof. Thus triangular fins are formed which act as stabilizing surfaces.

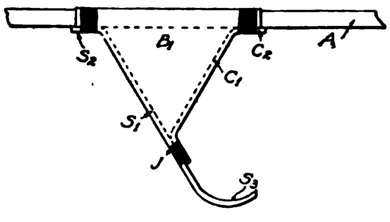

Fig. 5. Enlarged Details of One Rear Skid, Aeroplane Model

Main Planes. The main planes are two in number, but are different in size. Contrary to the practice followed in large man-carrying monoplanes, the front supporting surface is comparatively small in area and the rear supporting surface comparatively large. These supporting surfaces L and P are shown in detail in Figs. 6 and 7. It has been found that a surface of considerable area is required at the rear of the machine to support it, hence, the discrepancy in size. Although the two supporting surfaces differ in size, they are made in exactly the same manner, each consisting of a thin longitudinal piece of spruce R, to which cross pieces of bamboo Q are attached. In the smaller plane, Fig. 7, all the cross pieces are of the same size. In the larger plane, Fig. 6, the outer strips S are somewhat shorter than the others. Their length is 2½ inches, whereas the length of the strips Q is 3½ inches. In order to allow for the more gradual tapering of the plane, around the outer ends of the longitudinal strips R and the ribs Q a strip of bamboo O is tied. The frame, composed of the longitudinal strip and cross strips, is then covered with bamboo paper, parchment paper, or any other stiff light paper, which is glued in place.

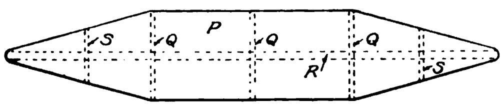

Fig. 6. Details of Main Plane of Aeroplane Model

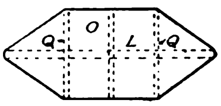

Fig. 7. Details of Smaller Plane of Aeroplane Model

The forward or smaller plane has a spread of 8½ inches and a depth of 3¼ inches. The main plane has a spread of 20 inches and a depth of 3½ inches at the widest portion. The author has made experiments which lead him to believe that the tapering form given to the outer edge of the plane improves both the stability and endurance of the machine.

The planes are slightly arched, although it will be found that flat planes will also give good results. The rear edge of the main plane should be placed 4¼ inches distant from the forward edge of the propeller block E_1.

The front plane must have a slight angle of incidence, just how much depends upon the weight of the machine, the manner in which it is made, and various other factors. This angle of incidence is obtained by resting the front portion of the plane on two small blocks *N*, Figs. 1 and 2, which are fastened to the top of the main strip *A* by strong thread and glue.

The height of the blocks *N* should be about ¼ inch, although this will necessarily vary with the machine. The blocks should be placed approximately 4 inches from the forward end of the machine. The front end of the forward plane should be elevated about ¼ inch above the rear end, which rests directly on the main strips.

Both the front and rear planes *L* and *P* are removably lashed to the frame by means of ordinary rubber bands, which may be obtained at any stationery store. These rubber bands are lettered *M* in Fig. 1.

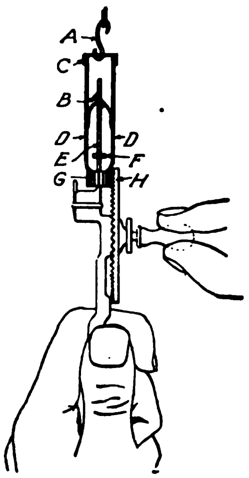

Fig. 8. Device for Winding up Rubber-Band Motors

Winding the Rubber Strips. The rubber strips can be most conveniently wound up by means of an egg beater, slightly changed for the purpose, Fig. 8. The beater and the frame in which it is carried are entirely removed, leaving only the main rod *E*, which is cut off at the lower end so that the total length is not more than 2 or 3 inches. The two brass strips *D* on either side of the rod, which are attached to the pinion *Q* meshing with the large driving wheel *H*, are likewise retained. A washer *F* is soldered to the rod near its upper end, so as to limit the motion of the small pinion *G* and the brass strips *D* attached to the pinion. Next a wire *B* is bent in the form of a loop, through which loop the central rod passes. The ends of the wire are soldered to the side strips *D*. Lastly, a piece of wire *C* is bent and soldered to the lower ends of the side strips. In order to wind up a rubber strip, the strip is detached from the forward end of the model, and the hook *A* slipped over the wire *C*. The opposite end of the rubber band is held in any convenient manner. Naturally the two strips must be wound in opposite directions, so that the two propellers will turn in opposite directions. By stretching the rubber while it is being wound, more revolutions can be obtained. It is not safe to have the propeller revolve more than 700 times. The ratio of the gears of the egg-beater winder can be figured out so that the requisite number of twists can be given to the rubber bands for that particular number of revolutions.

Model with Gasoline Motor. The next and somewhat more ambitious stage is the building of a power-driven model, which has been made possible by the manufacture of miniature gasoline motors and propellers for this purpose. Motors of this kind, weighing but a few pounds and capable of developing ¼ horse-power or more, may be had complete with an 18-inch aluminum propeller and accessories for about $45. As is the case with the rubber-band driven model, the monoplane is the simplest type to construct, and the dimensions and details of an aeroplane of this type are given here. It will be found that a liberal-sized machine is required to support even such a small motor. The planes, Fig. 9, have a spread of 7 feet 8 inches from tip to tip, each wing measuring 3½ feet by a chord of 15 inches. They are supported on a front and rear wing spar of spruce, ½ by ⅜ inch in section, while the ribs in both the main plane and the rear stabilizing plane measure ⅛ by ½ inch in cross section. There are eight of these spruce ribs in the main plane, and they are separately heated and curved over a Bunsen burner, or over a gas stove, which is the same thing. They are then nailed to the wing spars 6 inches apart. The main spars of the fuselage are 7 feet long and they are made of ½- by ⅜-inch spruce, the struts being placed 1½ feet apart, measuring from the rear, with several intermediate struts to brace the engine bed. Instead of using strut sockets for the fuselage, which would increase the cost of construction unnecessarily, a simple combination of a three-way wire fastener and a wire nail may be resorted to. The shape of these fasteners is shown at *A* in Fig. 9. They may be cut out of old cracker boxes or tin cans (sheet iron) with a pair of shears, the holes in the ends being made either with a small drill or by driving a wire nail through the metal placed on a board, and filing the burrs off smooth. A central hole must also be made for the 1½-inch wire nail which is driven through the main spar and the fastener then slipped over it. As indicated, this nail also serves to hold the strut. A drop of solder will serve to attach the fastener to the nail. The front of the fuselage is 9 inches square, tapering down to 6 inches at the rear. The height of the camber of the main planes

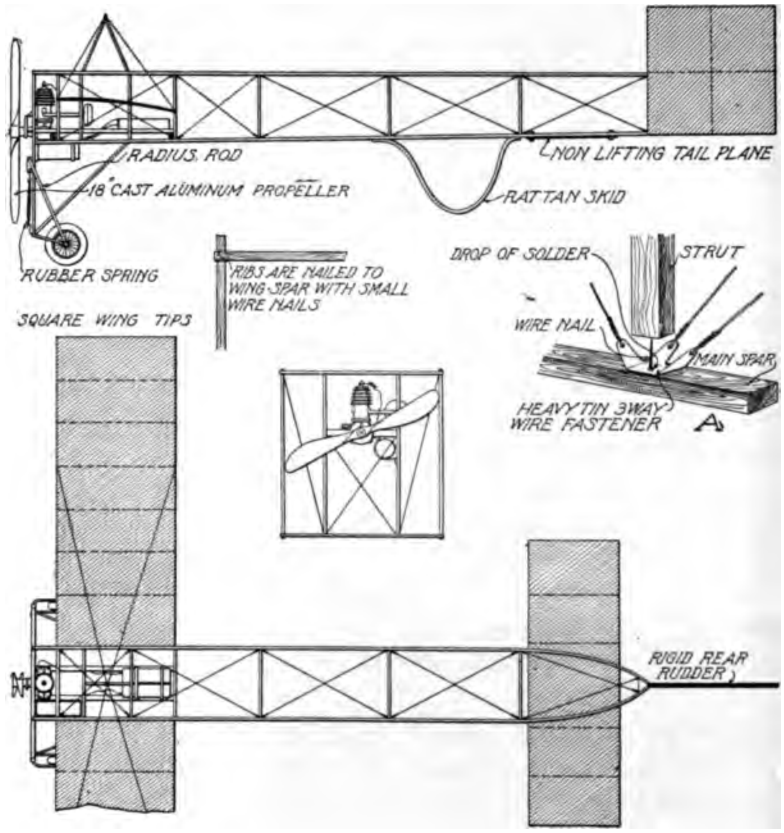

Fig. 9. Details of Power-Driven Aeroplane Model

is 1½ inches and the angle of incidence is 7 degrees, measured with relation to the fuselage. The non-lifting tail plane at the rear which is to give the machine longitudinal stability, measures 4 feet in span by 14 inches in depth.

The running gear or front landing frame is made of ½-inch square spruce, all joints being made with 1/16- by 1-inch bolts. Aluminum sleeves, procurable at an aeronautic supply house, are employed for the attachment of the rubber springs and the radius rods running down to the wheels, which may also be purchased ready to install. Old bicycle wheels will serve the purpose admirably. Light steel tubes ¼ inch in diameter are used to run these aluminum sleeves on. Two other steel tubes are joined to the lower corner of the frame by flattening them at the ends and drilling with a small hole for a nail. These are run diagonally up to the fuselage and serve as buffers to take the shocks of landing. For bracing the wings, two similar tubes are fastened to form a pyramid on top of the main plane just back of the engine. From these, guys are run to the wings as shown. The engine bed is made of ½- by ¾-inch white pine, and to make it solid it is carried as far back as the rear edge of the main plane. The batteries and coil are directly attached to this plane, care being taken in their placing to preserve the balance of the machine. The rudder measures 14 inches square and is made of ⅜-inch square spruce, reinforced with tin at the joints, as it is necessary to make the frame perfectly rigid. Both sides are covered with fabric. In this case a 1-horse-power motor furnishes the necessary energy and it is fitted with an 18-inch aluminum propeller which it is capable of turning at 2,400 r. p. m. The carbureter and gas tank are made integral, and the gasoline and oil are both placed in this tank in the proportion of about four parts to one, in order to save the weight of an extra tank for oil.

Flights of half a mile are possible with this model in calm weather, but a great deal of measuring and testing of the fuel is necessary in order to regulate the flight, and "grass-cutting" should be practiced by the builder in order to properly regulate the machine. Trials have shown that the flat non-lifting tail on the fuselage gives excellent longitudinal stability, the machine rising nicely and making its descent very easy angle, so that it is seldom damaged by violent collisions in landing.

BUILDING A GLIDER

The building of hand- or power-driven models does not suffice to give that personal experience that most students are desirous of obtaining. The best method of securing this is to build a glider and practice with it. Any flying machine without a motor is a glider and the latter is the basis of the successful aeroplane. In the building of an aeroplane the first thing constructed is the glider, *i. e.*, the frame, main planes, stabilizing planes, elevators, rudders, etc. It is only by the installation of motive power that it becomes a flying machine. The biplane will be found the most satisfactory type of glider as it is more compact and therefore more easily handled, which is of great importance for practicing in a wind. The generally accepted rule is that 152 square feet of surface will sustain the weight of the average man, about 170 pounds, and it will be apparent that the length of the glider will have to be greater if this surface is to be in the form of a single plane than if the same amount is obtained by incorporating it in two planes—the biplane. A glider with a span of 20 feet and a chord of 4 feet will have a surface of 152 square feet. So far as learning to balance and guide the machine are concerned, this may be mastered more readily in a small glider than in a large one, so that there is no advantage in exceeding these dimensions—in fact, rather the reverse, as the larger construction would be correspondingly more difficult to handle. The materials necessary consist of a supply of spruce, linen shoe thread, metal sockets, piano wire, turnbuckles, glue, and closely-woven, light cotton fabric for the covering of the planes.

Main Frame. The main frame or box cell is made of four horizontal beams of spruce 20 feet long and 1½ by ¾ inch in section. They must be straight-grained and perfectly free from knots or other defects. If it be impossible to obtain single pieces of this length, they may be either spliced or the glider may be built in three sections, consisting of a central section 8 feet long, and two end sections each 6 feet in length, this form of construction also making the glider much easier to dismantle and stow in a small space. In this case, the ends of the beams of each end section are made to project beyond the fabric for 10 inches and are slipped into tubes bolted to corresponding projections of the central section. These tubes are drilled with three holes each and bolts are passed through these holes and corresponding holes in the projecting ends after they have been fitted into the tubes, and drawn up tightly with two nuts on each bolt to prevent shaking loose. Ordinary $\frac{3}{16}$-inch stove bolts will serve very nicely for this purpose. The upper and lower planes forming the box cell, are held apart by 12 struts, 4 feet long by $\frac{7}{8}$ inch diameter, preferably of rounded or oval form with the small edge forward to minimize the head resistance. It is only necessary to space these equally, starting from both ends; this will bring the splices of the demountable sections in the center of the square on either side of the central section. The main ribs are 3 feet long by $1\frac{1}{4}$- by $\frac{1}{2}$-inch section and their placing should coincide with the position of the struts. Between these main ribs are placed 41 small ribs, equally spaced and consisting of pieces 4 feet long by $\frac{1}{2}$ inch square. These, as well as all the other pieces, should have the sharp edges of the square rounded off with sand paper. The ribs should have a camber of 2 inches in their length and the simplest method of giving them this is to take a piece of plank, draw the desired curve on it, and then nail blocks on both sides of this curve, forming a simple mould. The rib pieces should then be steamed, bent into this mould, and allowed to dry, when they will be found to have permanently assumed the desired curvature. Meanwhile, all the other pieces may be shellaced and allowed to dry.

Assembling the Planes. To assemble the glider, the beams are laid out on a floor, spaced the exact distance apart, *i. e.*, 3 feet, and exactly parallel—in the demountable plan, each section is assembled independently. The main ribs are then glued in place and allowed to set, after which they are strongly bound in place with the linen thread, and the various layers of thread given a coating of hot glue as they are put on. This method is not arbitrary, but it is simple and gives the lightest form of construction. If desired, tie-plates, clamps, or any other light method of fastening may be employed. This also applies to the ribs. They are assembled by placing them flush with the front beam and allowing them to extend back a foot beyond the rear beam, arched side up in every case. They may be glued and bound with thread, held by clamps, or nailed or screwed into place, care being taken to first start a hole in the beam with an awl and to dip the nails in soft soap to prevent splitting the wood. Twenty-one ribs, spaced one foot apart, are used in the upper plane, and 20 in the lower, owing to the space left for the operator in the latter. For fastening the two planes together, whether as a whole or in sectional units, 24 aluminum sockets will be required. These may be purchased either ready to fit, or an effective substitute made by sawing short lengths of steel tubing, slitting them with the hack saw an inch from the bottom, and then flattening out and drilling the right-angle flanges thus formed to take screws for attaching the sockets to the beams. In case these sockets are bought, they will be provided with eye bolts for the guy wires; if homemade, they may have extra holes drilled in the edges of the flanges for this purpose or some simple wire fastener such as that described in connection with the power-driven model may be used, heavier metal, however, being employed to make them. The sockets should all be screwed to the beams at the proper points and then the struts should be forced into them. The next move is to "tie" the frame together with guy wires, No. 12 piano wire being employed for this purpose. Each rectangle is trussed by running diagonal guy wires from each corner to its opposite. To pull these wires taut, a turnbuckle should be inserted in each and after the wire has been pulled as tightly as possible by hand, it should be wound upon itself to make a good strong joint, as shown at *B*, Fig. 6. A fastening as shown at *A* will pull out under comparatively little strain and is not safe. As is the case with most of the other fittings, these turnbuckles may be bought or made at home, the simple bicycle type of turnbuckle mentioned in connection with "Building a Curtiss," being admirably adapted to this purpose. In fact, the construction of the latter will be found to cover the requirements of the glider, except that the ribs are simpler and lighter, as already described, and no provision for the engine or similar details is necessary. All the guy wires must be tightened until they are rigid, and the proper degree of tension for them may be simply determined in the following manner:

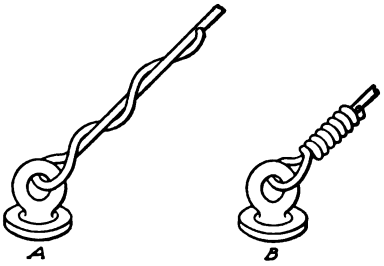

Fig. 10. Wrong and Right Way of Making a Wire Joint

After the entire frame is wired, place each end of it on a saw horse so as to lift it two or three feet clear of the floor. Stand in the opening of the central section, as if about to take a glide, and by grasping the forward central struts, raise yourself from the floor so as to bring your entire weight upon them. If properly put together the frame will be rigid and unyielding, but should it sag even slightly, the guy wires must be uniformly tightened until even the faintest perceptible tendency to give under the weight is overcome.

Stretching the Fabric. The method of attaching the fabric will be determined by whether the glider is to be one piece or sectional, and the expense for this important item of material may be as little or as much as the builder wishes to make it. Some employ rubberized silk, others special aeronautic fabrics, but for the purposes of the amateur, ordinary muslin of good quality, treated with a coat of light varnish after it is in place, will be found to serve all purposes. The cloth should be cut into 4-foot strips, glued to the front horizontal beams, stretched back tightly, and tacked to both the rear horizontal beams and to the ribs. Tacks should also supplement the glue on the forward beams and the upholstery style should be used to prevent tearing through the cloth. In case the glider is built in sections, the abutting edges of the cloth will have to be reinforced by turning it over and stitching down a strip one inch wide, and it will make this edge stronger if an extra strip of loose fabric be inserted under the turn before sewing it down. Eyelets must then be made along these edges and the different sections tightly laced together when assembling the glider. It is also desirable to place a strip of cloth or light felt along the beams under the tacks to prevent the cloth from tearing out under the pressure.

To form a more comfortable support for the operator, two arm pieces of spruce, 3 feet by 1 inch by 1¾ inches, should be bolted to the front and rear beams about 14 inches apart over the central opening left in the lower plane. These will be more convenient than holding on to the struts for support, as it will not be necessary to spread the arms so much and there will be more freedom for manipulating the weight to control the glider in flight. In using the struts, it is customary to grasp them with the hands, while with the arm pieces, as the name implies, the operator places his arms over them, one of the strips coming under each armpit. After the fabric has been given a coat of varnish on the upper side and allowed to dry, the glider is ready for use. The cost of the material should be about $30 to $40, depending upon the extent to which the builder has relied upon his own ingenuity in fashioning the necessary fittings—in any case, it will be less than the amount required for the purchase of the engine alone for a power-driven model.

Glider with Rudder and Elevator. It will be noted that this is the simplest possible form of glider in that it is not even provided with a rudder, but for the beginning of his gliding education the novice will not require this, as first attempts should be confined to glides over level ground in moderate, steady wind currents and at a modest elevation. Some of the best gliding flights made by Herring, Chanute's co-worker, were in a rudderless glider. After having mastered the rudiments of the art, the student may go as far as the dictates of his ambition impel him in the direction of improvements in his glider, by adding a rudder, elevator, and warping control. In fact, it is not necessary to confine himself to the simple design of glider here outlined at all. He may take either the Wright or Curtiss machines as a model and build a complete glider, following the dimensions and general methods of construction here given, though these may also be improved upon by the man handy with tools, bearing in mind that the object to be achieved is the minimum weight consistent with the maximum strength.

Learning to Glide. The first trials should be made on level ground and the would-be aviator should be assisted by two companions to help him in getting under way. The operator takes a position in the center rectangle, back far enough to tilt up slightly the forward edges of the planes. A start and run forward is made at a moderate pace, the keepers carrying the weight of the glider and overcoming its head resistance by running forward at the same speed. As the glider cuts into the air, the wind caused by running will catch under the uplifted edges of the curved planes and will buoy it up, causing it to rise in the air taking the operator with it. This rise will be probably only sufficient to lift him clear of the ground a foot or two. Now he projects his legs slightly forward so as to shift the center of gravity a trifle and bring the edges of the glider on an exact level, parallel with the ground. This, with the momentum acquired at the start, will keep the glider moving forward for some distance. When the weight of the operator is slightly back of the center of gravity, the leading edges of the planes are tilted up somewhat, increasing the angle of incidence and in consequence the pressure under the planes, causing the glider to rise, and if the glide is being made into a wind, as should always be the case, quite a height may be reached as the result of this energy. Once it ceases, the tendency to a forward and upward movement is lost, and it is to prolong this as much as possible that the operator shifts the center of gravity to bring the machine on an even keel, or where at a little height, slightly below this, giving it a negative angle of incidence, which permits him to coast down the air until sufficient speed is acquired to reverse the angle of incidence and again rise so as to provide a "hill" for another coast, thus prolonging the flight considerably. To put it in the simplest language, when the operator moves backward, shifting the center of gravity to the rear, the planes are tilted so that they catch or "scoop up" the advancing air and rise upon it, whereas when he moves forward and the planes tilt downward, this air is "spilled" out behind and no longer acts as a support, and the glider coasts, either until the ground is reached or enough momentum is gained to again mount upon the wind. A comparatively few flights will suffice to make the student proficient in the control of his apparatus by his body movements, not only as concerns the elevating and depressing of the planes to ascend or descend, corresponding to the use of the elevator on a power machine, but also actual steering, which is accomplished by lateral movement to the left or right.

Stable equilibrium is one of the chief essentials to successful flight and this can not be maintained in an uncertain, gusty wind, especially by the novice. The beginner should certainly not attempt a glide unless the conditions are right. These are a clear, level space without obstructions such as trees, and a steady wind not exceeding 12 miles per hour. When a reasonable amount of proficiency has been attained in the handling of the glider over level ground, the field of practice may be changed to some gentle slope. In starting from this, it will be found easier to keep the glider afloat, but the experience at first will prove startling to the amateur, for as the glider sails away from the top of the slope, the distance between him and the ground increases so rapidly that he will imagine himself at a tremendous height, but by preserving the balance and otherwise manipulating his weight in the manner taught by the practice over the level, a nice flight of much greater distance will be made and the machine will gradually settle down to the ground much farther away from the starting place than was possible in the earlier trials, this being one of the great advantages of starting from an elevation. There is nothing that will fit the beginner so well for the actual handling of a power machine as a thorough course of gliding flights, and it is recommended that those who build gliders become proficient in their use before attempting to pilot an aeroplane, whether of their own make or not.

A further step in advance is the actual building of a full-fledged power machine, and for those who desire a simple and comparatively inexpensive type, requiring very little work that can not be performed in the home workshop, a description of the construction of a Curtiss biplane is given, while for those who are more ambitious and also have greater financial resources, the details of the building of a Bleriot monoplane are given.

BUILDING A CURTISS BIPLANE

Cost. First of all, the prospective builder will want to know the cost. The best answer to this is that the machine will cost all its builder can afford to spend upon it and probably a little more, as the man to whom the expense is not of vital consideration will doubtless not undertake its construction. Speaking generally, and there can be nothing very definite about it, in view of the great difference in the conditions, an expenditure of three to four hundred dollars will cover the complete outlay for everything but the motor. If the builder has the time and facilities for doing all the work himself, this amount may be reduced very materially. On the other hand, if he finds it necessary to purchase most of the material in form ready to assemble, it may exceed this. But it will be a great aid to many to know that there is practically nothing about the modern aeroplane which can not be found in stock at one of the aeronautic supply houses. This makes it possible for many to undertake the construction of a machine to whom it would not be feasible, or at least not an attractive project in view of the time involved, were it necessary to make every part at home. So far

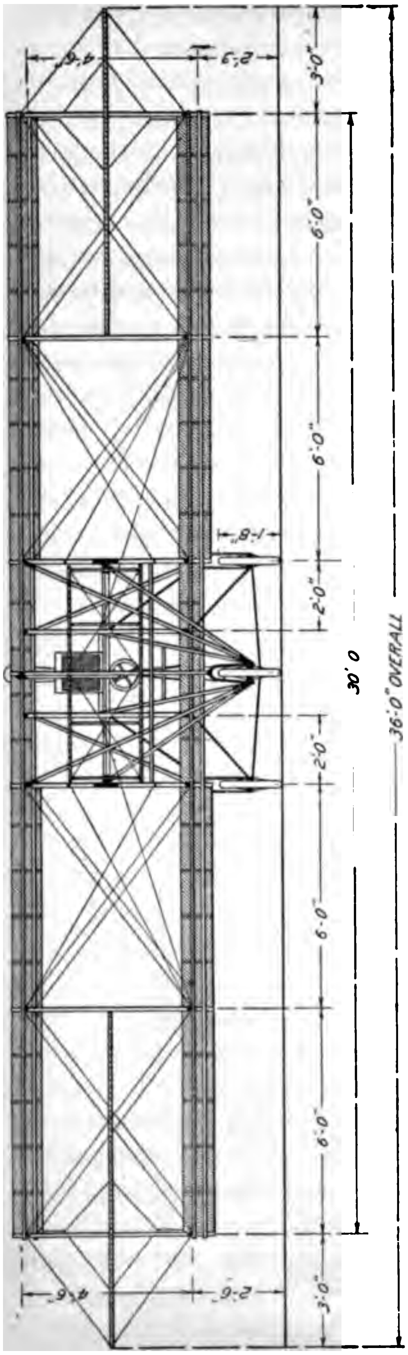

Fig. 11. Detailed Front View of Curtiss Biplane

as becoming involved in any legal difficulties is concerned owing to existing patents, the student need not worry himself about this in attempting the construction of a Curtiss biplane, so long as he restricts the use of his machine to experimental purposes and does not try to compete with the patentees in their own field—that of exhibiting and selling machines.

General Specifications. Just how long it will take to complete such a machine will depend very largely upon the skill of the builder and the extent of his resources for, as already mentioned, the expense may be cut down by making all the necessary parts at home, but it will naturally be at the sacrifice of a great deal of time. For instance, the oval struts and beams may be bought already shaped from the local planing mill, or they may be shaved down from the rough by hand. Turnbuckles can be made from bicycle spokes and nipples and strips of sheet steel, or they can be bought at 12 to 15 cents each. As a hundred or more of them are needed, their cost is quite a substantial item.

Aeroplane construction doubtless impresses the average observer as being something shrouded in considerable mystery—something about which there is no little secrecy. Quite the contrary is the case in reality. Any man who is fairly proficient as a carpenter and knows how to use the more common machinist's tools, such as taps and dies, drills, hacksaw, and the like, will find no difficulty in constructing the machine of which the details are given here. Having completed its building, he will have to draw upon his capital to supply the motor. One capable of developing 25 to 30 horse-power at 1,000 to 1,200 r. p. m. will give the machine considerable speed, as it will be recalled that Curtiss made a number of his first flights

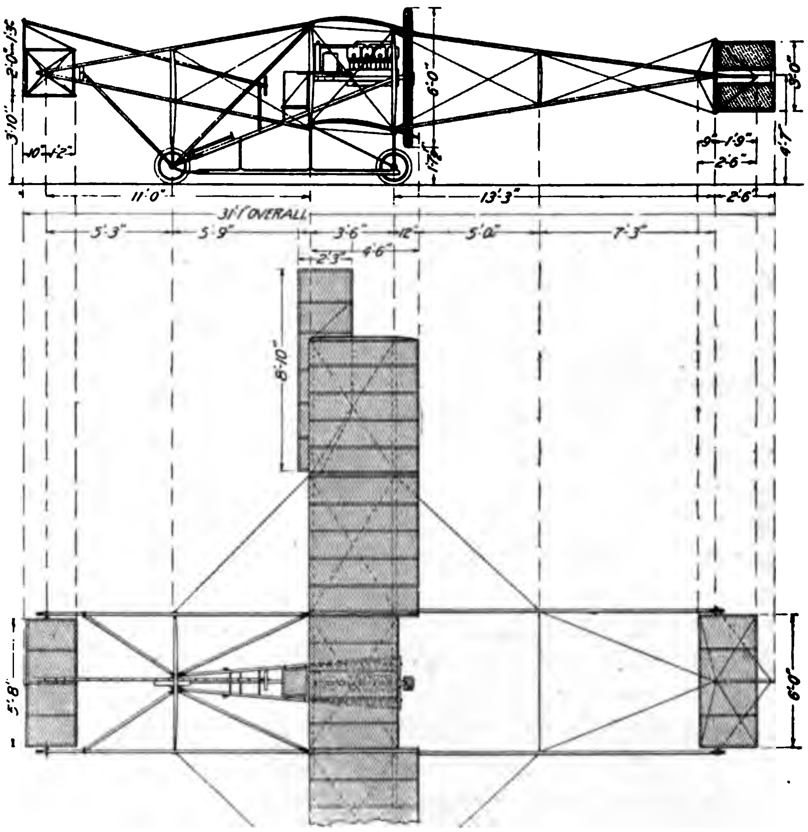

Fig. 12. Plan and Side Elevation of Curtiss Biplane

with a 25-horse-power motor. As to the weight, the lighter the better, but 400 pounds for the complete power plant will not be excessive. The machine can sustain itself in the air with less power than that mentioned, but with a heavy, low-power motor it will be sluggish in action. This is an advantage for the amateur, rather than otherwise, as it will provide him with an aeroplane that will not be apt to get away from him during his first trials, thus making it safer to learn on.

The Curtiss biplane has a spread of 30 feet, the main planes or wings being divided into sections of a length equal to the distance between struts, Figs. 11 and 12. There are five of these sections, each measuring six feet. The struts can be taken out and the sections laid flat on each other for storage. The framework for the front and rear rudders can also be jointed, if desired, making it possible to store the machine in small compass. The longest parts of the machine, when taken apart, are the two diagonal beams running from the front wheel back to the engine bed, and the skid. The horizontal front rudder is packed intact. The vertical rear rudder is unhung and laid flat on the tail. Two men can take the machine apart in a few hours, and can reassemble it in a day. Whether these particular

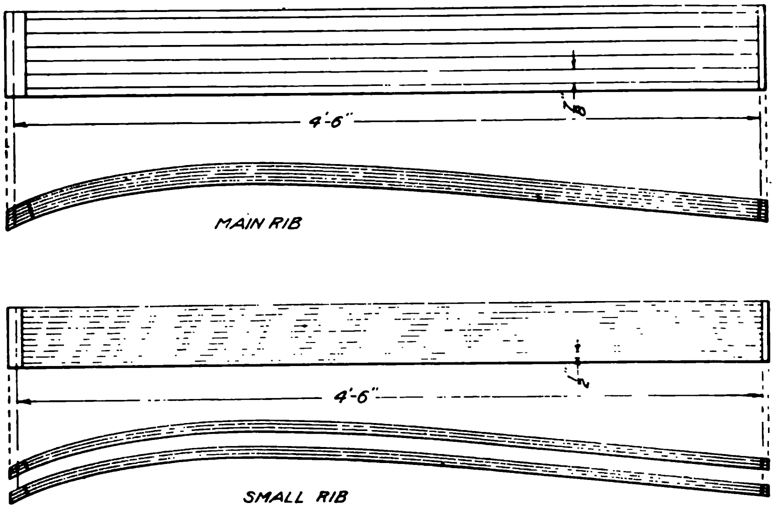

Fig. 13. Details of Main and Small Ribs, Curtiss Biplane

TABLE I

Relative Strength of Clear Spruce and Elm as Demonstrated by Tests

Material	Size of Pieces (Inches)	Breaking Strain (Pounds)	Weight of Piece (Ounces)
Elm	1½ ×1⅛ ×12	900	5¼
Spruce	1½ ×1⅛ ×12	900	4¼
Elm	1 1/16×1 1/16×12	880	4¾
Spruce	1 1/16×1 1/16×12	760	3⅞
Elm	1 ×1 ×12	450	4
Spruce	1 ×1 ×12	600	3½
Elm	13/16×1⅛ ×12	390	3½
Spruce	13/16×1⅛ ×12	475	3
Elm	¾ × ¾ ×12	275	2½
Spruce	¾ × ¾ ×12	280	2¼
Elm	9/16×13/16 ×12	175	2⅛
Spruce	9/16×13/16 ×12	175	2

features of construction are covered by patents can not be said, as Curtiss has declined to commit himself regarding any rights he may have to them.

Ribs. Two distinct types of ribs are used, main ribs and small ribs, both of the same curvature, Fig. 13. The main ribs are used between pairs of struts, to hold apart the front and rear beams; they are heavy enough to be quite rigid. Three to four small ribs are laid across each section of the planes, between the pairs of main ribs, to give the cloth the proper curvature, and to maintain it in the form desired. The main ribs are built up of six ¼-inch laminations of wood ⅞ inch wide and securely glued together. The small ribs are made of three layers ½ inch wide.

The first part of the actual construction will be the making of these laminated ribs, but before describing this detail, the question of suitable material should be well considered. Both weight and strength must be figured on and this limits the choice to a few kinds of wood. Of these *spruce* and *elm* are the best available, with the occasional use of *ash* to give greater rigidity. Spruce is, of course, the first choice. This wood was once considered as having no great strength, but a series of careful tests shows this belief to be unfounded. With the exception of the bed, or support for the motor and a few other parts, the Wright machines are constructed wholly of spruce.

Table I gives results of tests made with spruce from Washington and Oregon, and with elm from Michigan and Indiana. Testing scales were employed, the pieces being supported at their ends with the load in the center.

These tests were made with clear wood in each case, as knots naturally decrease the strength of a piece greatly, this depending on their size and location.

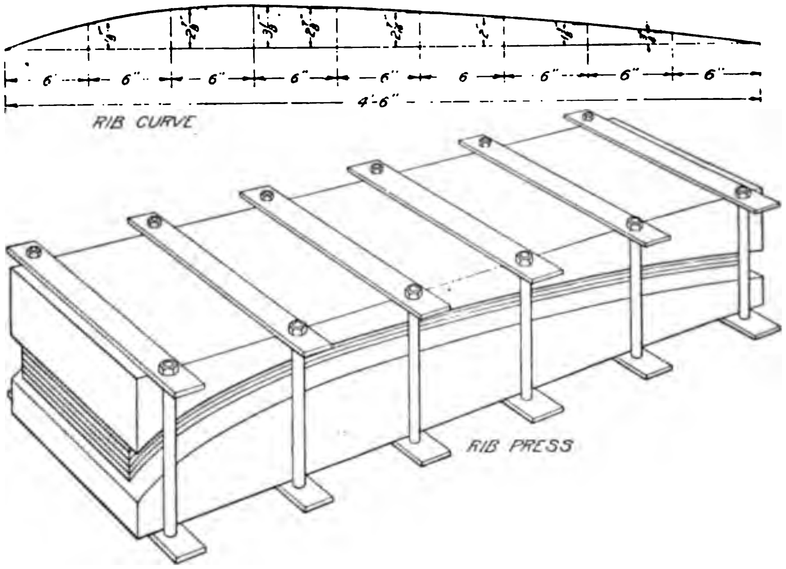

Fig. 14. Details of Rib Press, Curtiss Biplane

Before proceeding with the ribs themselves, the press for giving them the proper curvature must be made. Take a good piece of oak, ash, or other solid wood, 8 inches wide by 5 feet long, and dressed all over. On the side of the piece lay out the curve, the dimensions of which are illustrated in Fig. 14. First, rule the horizontal, or chord line, on it, marking off 4 feet 6 inches on this line, equidistant from each end. Then divide the chord into 6-inch sections and, at the point of each 6-inch section, erect perpendiculars beginning at the rear, $\frac{3}{4}$ inch, 1$\frac{5}{8}$ inches, 2 inches, and so on, as indicated on the drawing. The upper ends of these perpendiculars will form locating points for the curve. Through them draw a smooth curve as shown, continuing it down through the chord at each end. Take the piece with the curve thus marked on it to the local planing, sash and blind, or sawmill—any plant equipped with a band saw—and have it cut apart along the curve. This will cost little or nothing—acquaintance will obtain it as a favor, and acquaintance with any wood-working concern in the aeroplane builder's home town will be of great aid. Failing this aid, the operation may be carried out with a hand saw (rip), but the job will not be as neat and will have to be cleaned up with a draw knife and sand paper, taking care to preserve the outline of the curve as drawn. As the rib press is really a mould or pattern from which all the ribs are to be bent to a uniform curvature, care must be taken in its construction.

To clamp the two halves of the press together, a dozen machine bolts will be required; they should measure ¾×15 inches. If obtainable, eye bolts will be found more convenient as they may be turned up with but one wrench and a bar. The steel straps are ⅜ by 1½ by 10 inches long with ¾-inch holes drilled 9 inches apart to centers, to enclose the 8-inch pieces.

Obtain a sufficient supply of boards of reasonably clear spruce, ¼ inch thick, 6 to 7 inches wide, and at least 4 feet 9 inches long (dressed both sides), to make all the ribs necessary both small and large. This material should be purchased from the mill as it is out of the question to attempt to cut the ribs from larger sizes by hand. Buy several pounds of good cabinet makers' glue and a water-jacketed gluepot. This glue comes in sheets and in numerous grades—a good quality should be used, costing from 40 to 50 cents a pound if bought in a large city. Laminating the ribs in this manner and gluing them together is not only the quickest and easiest method of giving them the proper curve, being much superior to steam bending, but is also stronger when well done, as the quality of the material can be watched more closely.

Start with the making of the small ribs; apply the glue thin and piping hot in a generous layer to three boards with a good-sized flat paint or varnish brush. Omit on the upper surface of third board and apply between three others, Fig. 13. This will give two series of three each in the press. Tighten up the end bolts first, as the upper part of the press near the top of the curve is likely to be weak

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unless liberally proportioned. Then turn down the nuts on the other bolts. Do not attempt to turn any one of them as far as it will go the first time, but tighten each one a little at a time, thus gradually making the compression over the whole surface as nearly uniform as possible. This should be continued until the glue will no longer ooze out from between the boards, indicating that they are in close contact. Twenty-four hours should be allowed for drying, and when taken out the cracks between the boards should be almost invisible in the finished ribs.

Have the laminated boards cut by a power rip saw at the planing mill, to the dimensions shown in the drawing, making an allowance of $\frac{1}{4}$ inch for the width of the saw blade at each cut in calculating the number of ribs which can be cut from each board. In addition, a margin should be allowed at each side, as it is impractical to get all the thin boards squarely in line. For the main ribs, apply the glue between all six boards, clamp and dry in the same manner. Thirty small ribs will be required, if three are used in each section, and forty if four are specified, while twelve main ribs will be needed for standard construction, and sixteen if the quick-demountable plan referred to is followed. It is advisable to make several extra ribs of each kind in addition. If the builder has not sufficient faith in spruce alone, despite the figures given in Table I, one of the laminations, preferably the center, or if two be employed, the outer ones, may be of ash, though this will add considerably to the weight.

To prevent the ribs from splitting open at the ends, they are protected by light steel ferrules, shown in Fig. 15. When received in the rough-sawed condition from the mill, the ribs must be tapered at the ends with a plane or spoke shave to fit these ferrules, and the sharp edges should be rounded off. In doing this, it must be remembered that the upper surface of the small ribs gives the curvature to the cloth surface, so that any tapering must be done on the lower side. The main ribs may be tapered from both sides, as it is the center line, or crack between the third and fourth laminations, that determines the curve. Every inch along this line $\frac{1}{16}$-inch holes are to be drilled for the lacing, Fig. 15.

The ferrules for the front ends of the small ribs are light $\frac{1}{2}$-inch seamless steel tubing; they may be flattened to the proper shape in a vise without heating and are drilled with a $\frac{1}{8}$-inch hole. They are driven tight on to the tapered ends of the ribs and fastened in place with a small screw. The rear-end ferrules are $\frac{1}{2}$-inch lengths of $\frac{3}{8}$-inch tubing, driven on and drilled with a $\frac{3}{32}$-inch hole for the rear-edge wire. The rear ferrules of the main ribs may be the same $\frac{1}{2}$-inch tubing used for the front of the small ribs; they should be cut off so that their ends will come in the same line as the holes in the ends of the small ribs. If the quick-demountable plan be followed, the second main rib from each end may be left long and drilled with a hole like the small ribs. The front ferrules of the main ribs should be $\frac{3}{4}$-inch tubing of heavier gauge, drilled with a $\frac{1}{4}$-inch hole. The finished ribs are sandpapered smooth and shellaced or coated with spar varnish. The latter is much more expensive and slower in drying but has the great advantage of being weatherproof and will protect the glue cracks from moisture. The ferrules may be painted with black enamel.

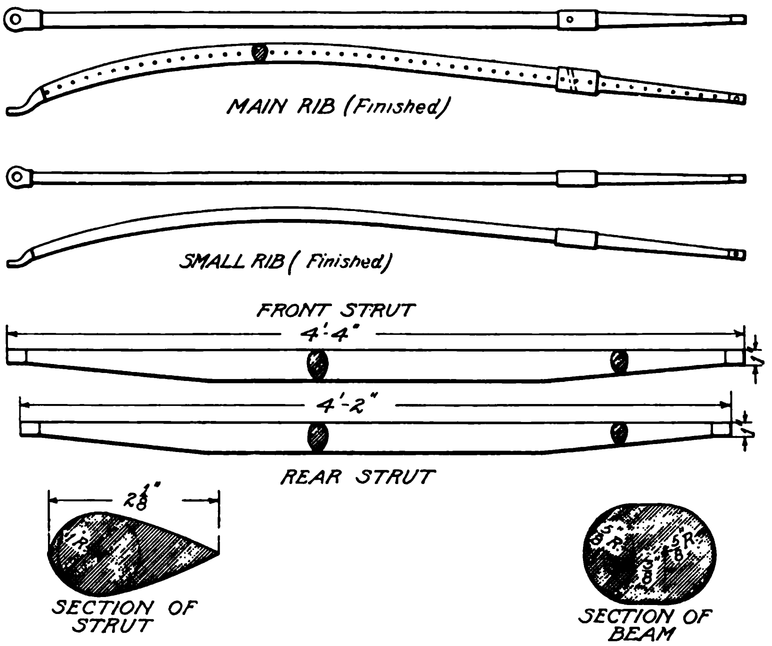

Fig. 15. Details of Ribs and Struts, Curtiss Biplane

Struts. Before going into the detail of the construction of the remainder of the *main cell* and its attached framing, a brief description of its parts and their relation to one another will make matters clearer. The upright struts, Fig. 15, which hold the two planes apart, fit at each end into sockets, which are simply metal cups with bolts projecting through their ends, Fig. 16. Those at the bottom of the front row of struts pass through the eyes of the turnbuckles and connections for the wire trussing, then through the flattened ferrules of the main ribs, and finally through the beam, all being clamped together with a nut. Those at the top go through the turnbuckles first, then through the beam, and finally the rib ferrule. The bolts at the back row of struts must go through the full thickness of the main ribs, and so must be longer. The drawings, Figs. 15 and 16, show the method of attachment of both the main and the small ribs and illustrate a neat method of attaching the turnbuckles—instead of being strung on the socket bolt one after another, they are riveted to the corners of a steel plate which alone is clamped under the socket.

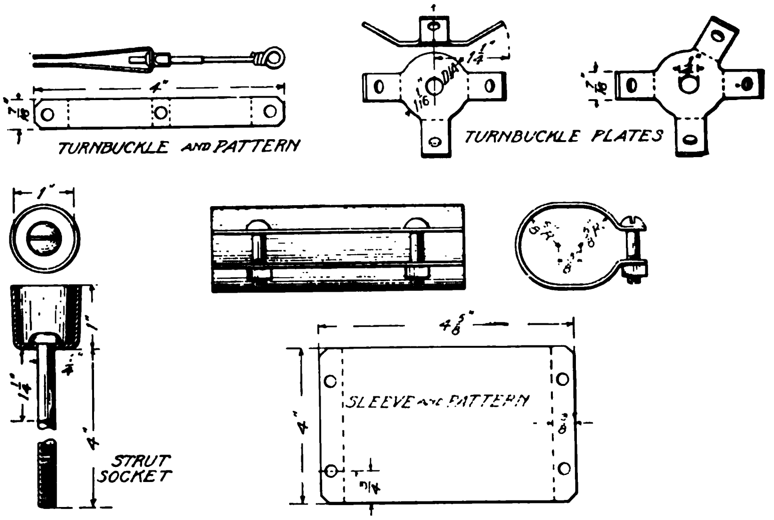

Fig. 16. Details of Metal Parts of Curtiss Biplane

Beams. The beams are jointed at each strut connection, the ends being cut square and united by a sheet-steel sleeve, a pattern of which is shown in Fig. 16, clamped on by two small bolts. The hole for the socket bolt is drilled half in each of the two abutting beams. As it is very difficult to obtain long pieces of wood sufficiently straight grained and free from knots for the purpose, this jointed system considerably cheapens the construction. Both beams and struts are of spruce, but to give additional strength, the beams of the middle section may be ash. Special aero cloth, rubberized fabrics, or light, closely-woven duck (racing yacht sail cloth of fine quality, this being employed at first by the Wright Brothers in their machines) forms the surfaces of the wings. The front edge of each section of the surface is tacked to the beam and the rear edge is laced over the rear wire already referred to, this wire being stretched taut through the holes in the rear tips of the ribs, both main and small. After the cloth is stretched tight, it is tacked to the small ribs, a strip of tape being laid under the tack heads to prevent the cloth from pulling away from under them. If the aeroplane is intended to be taken apart very often, the standard design as shown by the large drawings, Figs. 11 and 12, may be modified so as to make it unnecessary to unlace the cloth each time. This is arranged by regarding the two outer sections at each end of the plane as one, and never separating them. Additional main ribs are then provided at the inner ends of these sections, and are attached directly to the beams, instead of being clamped under the strut sockets. In taking the machine apart, the struts are pulled from the sockets, leaving the latter in place. It will then be an advantage to shorten the main planes somewhat, say 3 inches on each section, so that the outer double sections will come under the "12-foot rule" of the Express Companies.

Running Gear. Three wheels are provided—one in front under the outrigger and two under the main cell for starting and landing. Two beams extend from the front wheel to the engine bed and serve to carry the pilot's seat, as will be seen from the elevator, Fig. 12. A third beam runs back horizontally from the front wheel and on rough ground acts as a skid. The rest of the running gear is made of steel tubing, the pieces being joined simply by flattening the ends, drilling and clamping with bolts; no sockets or special connections of any kind are necessary here. If desired, the wheels may be carried in bicycle forks and may be fitted with shock absorbers, some idea of the various expedients adopted by different builders for this purpose being obtainable from the sketches, Fig. 40 in "Types of Aeroplanes." Two separate tubes, one on each side of the wheel make a simple construction and will probably serve just as well. The details of the running gear will be given later.

Outrigging and Rudders. For the outriggers and the frames carrying the front horizontal or elevating rudder and the rear vertical rudder and tail, or horizontal keel, either spruce or bamboo may be employed. Bamboo will be found on machines turned out by the Curtiss factory, and while it is the lighter of the two, it is not generally favored, as spruce is easier to obtain in good quality and is far easier to work. At their ends, these outriggers are fitted with ferrules of steel tubing, flattened and drilled through. The outriggers are attached to the main framework of the machine by slipping the ferrules over the socket bolts of the middle section struts, above and below the beams. It is preferable, however, to attach the rear outriggers to extra bolts running through the beams, so that when the machine is to be housed the tail and rudder can be unshipped and the triangular frames swung around against the main frame, considerably reducing the space required.

The tail, horizontal and vertical rudders, and the ailerons are light frames of wood, covered on both sides with the same kind of cloth as the main planes or wings. These frames are braced with piano wire in such a manner that no twisting strains can be put on them. The front horizontal rudder, which is of biplane construction like the main cell, is built up with struts in the same way. Instead of being fitted with sockets, however, the struts are held by long screws run through the planes and into their ends, passing through the eyes of the turnbuckles.

DETAILS OF CONSTRUCTION

Main Planes and Struts. It is preferable to begin with the construction of the main planes and their struts and truss wires, the ribs already described being the first step.

The main beams offer no special difficulties. They are ovals $1\frac{1}{4}$ by $1\frac{5}{8}$ inches, all 6 feet long except the eight end ones, which are 6 feet 2 inches. The beams of the central section should be of ash, or should be thicker than the others. In the latter case, they must be tapered at the ends so that the clamping sleeves will fit and the additional wood must be all on the lower side, so that the rib will not be thrown out of alignment. The spruce used for the other beams should be reasonably clear and straight grained, but a small knot or two does not matter, provided it does not come near the ends of the beam. The beams may be cut to the oval shape by the sawmill or planed down by hand.

"Fish-shaped" or "stream-line" section, as it is more commonly termed, is used for the struts, Fig. 15. It is questionable whether this makes any material difference in the wind resistance, but it is common practice to follow it in order to minimize this factor. It is more important that the struts be larger at their centers than at the ends, as this strengthens them considerably. At their ends the struts have ferrules of the 1-inch brass or steel tubing, and fit into the sockets which clamp the ribs and beams together. The material is spruce but the four central struts which carry the engine bed should either be ash or of larger size, say 1¼ by 3 inches.

Care Necessary to Get Planes Parallel. The front struts must be longer than the rear ones by the thickness of a main rib at the point where the rear strut bolt passes through it, less the thickness of the rib ferrule through which the bolt of the front strut must pass. However, the first distance is not really the actual thickness of the rib, but the distance between the top of the rear beam and the bottom of the strut socket. In the drawings the difference in length between the front and rear struts is given as 2 inches, but it is preferable for the builder to leave the rear struts rather long and then measure the actual distance when assembling, cutting the struts to fit. The ends of the struts should also be countersunk enough to clear the head of the socket bolt.

One of the items which the builder can not well escape buying in finished form is the strut sockets. These are cup-shaped affairs of pressed steel which sell at 20 cents each. Sixteen of them will be required for the main frame, and a dozen more can advantageously be used in the front and rear controls, though for this purpose they are not absolutely necessary. They can also be obtained in a larger oval size suitable for the four central struts that carry the engine bed, as well as in the standard 1-inch size. The bolts which project through the bottom of the sockets are ordinary ¼-inch stove bolts, with their heads brazed to the sockets.

For the rear struts, where the bolt must pass through the slanting main rib, it is advisable to make angle washers to put under the socket and also between the beam and rib. These washers are made by sawing up a piece of heavy brass tubing, or a bar with a $\frac{1}{4}$-inch hole drilled in its center, the saw cuts being taken alternately at right angles and at 60 degrees to the axis of the tube.

The sleeves which clamp together the ends of the beams are made of sheet steel of about 20 gauge. The steel is cut out on the pattern given in the drawing, Fig. 16, and the $\frac{3}{16}$-inch bolt holes drilled in the flanges. The flanges are bent over by clamping the sheet in a vise along the bending line and then beating down with a hammer. Then the sleeves can be bent into shape around a stray end of the beam wood. The holes for the strut socket bolts should not be drilled until ready to assemble. Ordinarily, $\frac{3}{16}$-inch stove bolts will do to clamp the flanges together.

Having reached this stage, the amateur builder must now supply himself with turnbuckles. As already mentioned, these may either be purchased or made by hand. It is permissible to use either one or two turnbuckles on each wire. One is really sufficient, but two—one at each end—add but little weight and give greater leeway in making adjustments. As there are about 115 wires in the machine which need turnbuckles, the number required will be either 115 or 230, depending upon the plan which is followed. Those of the turnbuckles to be used on the front and rear controls and the ailerons, about one-fifth of the total number, may be of lighter stock than those employed on wires which carry part of the weight of the machine.

Making Turnbuckles for the Truss Wires. On the supposition that the builder will make his own turnbuckles, a simple form is described here. As will be seen from Fig. 16, the turnbuckles are simply bicycle spokes, with the nipple caught in a loop of sheet steel and the end of the spoke itself twisted into an eye to which the truss wire can be attached. The sheet steel used should be 18 or 16 gauge, and may be cut to pattern with a heavy pair of tin snips: The spokes should be $\frac{3}{32}$ inch over the threaded portion. The eye should be twisted up tight and brazed so that it can not come apart. The hole in the middle of each strip is, of course, drilled the same size as the spoke nipple. The holes in the ends are $\frac{3}{16}$ inch.

In the original Curtiss machines, the turnbuckles were strung on the socket bolts one after another, sometimes making a pack of them half an inch thick. A much neater construction is shown in the drawings, in which the bolt pierces a single plate with lugs to which to make the turnbuckles fast by riveting. The plates are of different shapes, with two, three, or four lugs, according to the places where they are to be used. They are cut from steel stock $\frac{3}{32}$ inch thick, with $\frac{1}{4}$-inch holes for the socket bolts and $\frac{3}{16}$ inch, or other convenient size, for the rivets that fasten on the turnbuckles.

The relative merits of cable and piano wire for trussing have not been thoroughly threshed out. Each has its advantages and disadvantages. Most of the well-known builders use cable; yet if the difference between 1,000 feet of cable at $2\frac{1}{4}$ cents per foot (the price for 500-foot spools), and 8 pounds of piano wire at 70 cents a pound, looks considerable to the amateur builder, let him by all means use the wire. The cable, if used, should be the $\frac{3}{32}$-inch size, which will stand a load of 800 pounds; piano wire should be 24 gauge, tested to 745 pounds. It should be noted that there is a special series of gauges for piano wire, known as the music wire gauge, in which the size of the wire increases with the gauge numbers, instead of the contrary, as is usual with machinery wire gauges.

One by no means unimportant advantage of the piano wire is that it is much easier to fasten into the turnbuckles. A small sleeve or ferrule, a $\frac{1}{4}$-inch length of $\frac{1}{8}$-inch tubing, is first strung on the wire. The end of the wire is then passed through the turnbuckle eye, bent up, thrust through the sleeve, and again bent down. When the machine is taken apart, the wire is not disconnected from the eye, but instead the turnbuckle spoke is unscrewed from the nipple. The shape of the sheet-steel loop should be such as to hold the latter in place. Cable, on the other hand, must be cut with about 2 inches to spare. After being threaded through the turnbuckle eye, the end is wound back tightly on itself and then soldered, to make certain that it can not loosen.

With a supply of turnbuckles and cable or piano wire at hand, the builder may go ahead with the main box-like structure or cell, which should be completed except for the cloth covering, and in proper alignment, before taking up the construction of the running gear and controls.

Running Gear. The running gear of the machine is built of seamless steel tubing, those parts which carry the weight of the machine direct being of $\frac{3}{4}$-inch outside diameter, 16-gauge tubing, while the others are ⅝-inch outside diameter, either 18 or 20 gauge. About 25 feet of the heavy and 45 feet of the light tubing will be required, in lengths as follows: Heavy, four 3-foot, three 4-foot; light, one 6-foot, two 4-foot 6-inch, and seven 4-foot pieces. Referring to Fig. 17, two diagonal braces from the rear beam to the engine bed, the **V**-shaped piece under the front engine bed struts and all of the rear frame except the horizontal piece from wheel to wheel, are of heavy tubing. The horizontal in the rear frame, diagonals from the rear wheels and the rear end of the skid to the front beam, the two horizontals between the front and rear beam, and the forward **V** are of light tubing.

Three ash beams are used in the running gear. Two of these run diagonally from the rear end of the engine bed to the front wheel. These are about 10 feet long and 1 by 1¾ inches section. The third, which on rough ground acts as a skid, is 8½ feet long and about 2 inches square. Between the points where the tubing frames are attached to it, the upper corners may be beveled off with a spoke shave an inch or more down each side. The beams are attached to the front wheel with strips of steel stock 1½ inches wide and ⅛ inch thick. The engine bed beams are also ash about 1 by 1¾ inches section. Their rear ends are bolted to the middle of the rear engine bed struts and the front ends may be ½ inch higher.

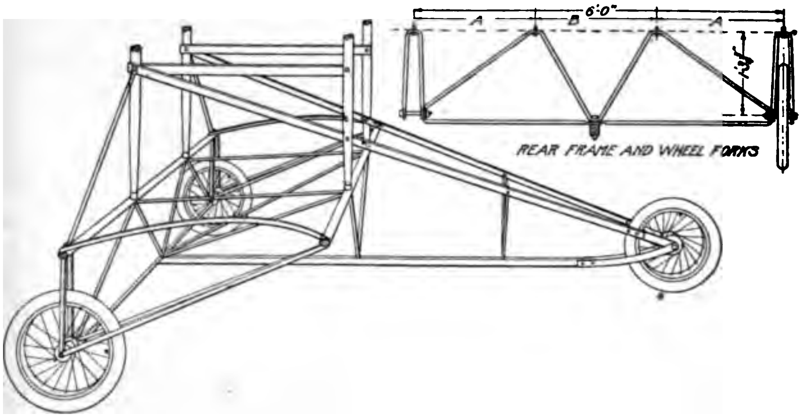

Fig. 17. Details of Curtiss Running Gear

The wheels are usually 20 by 2 inches, and of the bicycle type, but heavier and wider in the hub; the tires are single tube. These wheels, complete with tires, cost about $10 each. This size is used on the standard Curtiss machines, but novice operators, whose landings are not quite as gentle as they might be, find them easily broken. Therefore, it may be more economical in the end to pay a little more and get heavier tires—at least to start with.

For working the tubing into shape, a plumber's blow torch is almost indispensable—most automobilists will already possess one of these. The oval, flat variety, holding about one pint, is very handy and packs away easily, but on steady work requires filling somewhat too frequently. With a dozen bricks a shield can be built in front of the torch to protect the flame and concentrate the heat. Whenever it is to be flattened and bent, the tubing should be brought to a bright red or yellow heat. Screwing the vise down on it will then flatten it quickly without hammer marks. Where the bend is to be made in the middle of the piece, however, it may be necessary to resort to the hammer and anvil.

It is convenient to start with the framework under the rear beam. This may be drawn accurately to full size on the workshop floor, and the tubes bent to fit the drawing. With this framework once in place, a definite starting point for the remainder of the running gear is established. Here and in all other places, when boring through wood, the holes should be drilled out full, and larger washers should be placed under the bolt head and nut. All nuts should be provided with some sort of locking device The perspective drawing, Fig. 17, should show the general arrangement clearly enough to enable the builder to finish the running gear.

Outriggers. Both the front and rear control members, or "outriggers" as they are termed, Fig. 12, may be conveniently built up on the central section of the main frame, which, it is assumed, has now been fitted with the running gear.

The horizontal rudder, or "elevator," is a biplane structure like the main cell of the machine, but with fewer struts; it is carried in front of the main planes on two A-shaped frames. The vertical rudder, at the rear, is split along the middle and straddles a fixed horizontal plane, or *tail.* This also is carried on two A-shaped frames. Lateral stability is controlled by two auxiliary planes or ailerons, one at each side of the machine and carried on the two outer front struts. These three control units—*elevator*, *tail* and *rudder*, and *ailerons*—will now be taken up separately and their construction, location on the machine, and operation will be described.

Horizonal Rudder or Elevator. The two planes of the elevator are 2 feet wide by 5 feet 8 inches long and are spaced 2 feet apart, being held in this position by ten struts. The frames of the planes are built of spruce sticks ½ by 1 inch, each plane having two sticks the full length and five evenly spaced crosspieces or ribs. These are joined together with squares of X-sheet tin, as shown in the detailed drawing, Fig. 18. With a little experimenting,· paper patterns can be made from which the tin pieces can be cut out. The sticks are then nailed through the tin with ¾-inch brads.

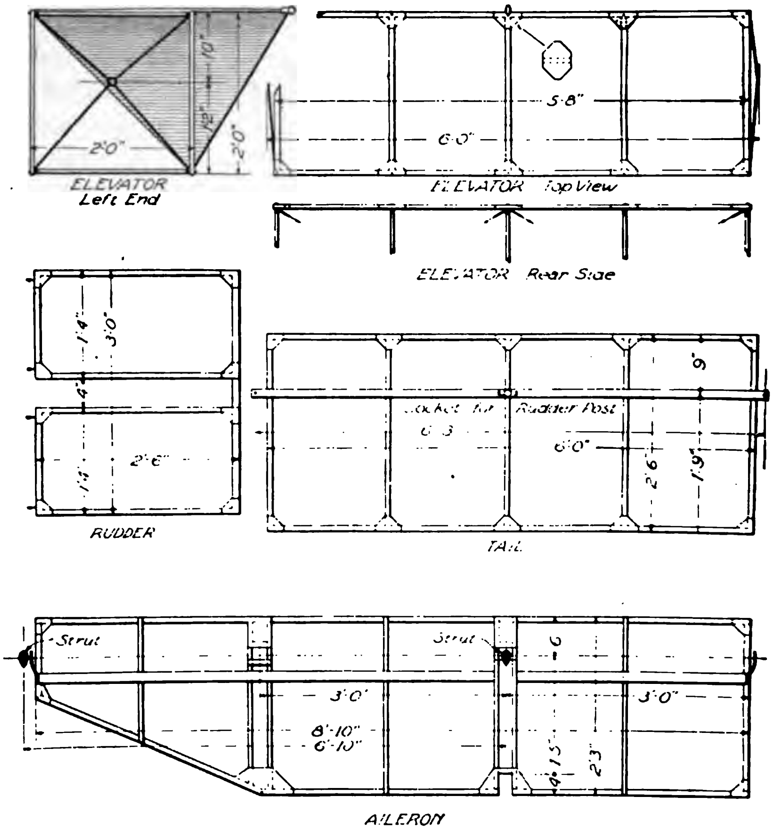

Fig. 18. Details of Rudders and Ailerons, Curtiss Biplane

It is convenient to draw the frames out accurately on a smooth wood floor and then work over this drawing. The first few brads will hold the sticks in place. When all the brads have been driven, a little drop of solder should be run in around the head of each one. This is a tedious job. One must be careful to use no more solder than necessary as it increases the weight very rapidly. Two pounds of wire solder should be sufficient for all the control members which are built in this way. When the top side is soldered, pry the frame loose from the floor with a screwdriver and turn it over. Then the projecting points of the brads must be clinched and the soldering repeated.

At this stage, the two frames should be covered on both sides with the prepared cloth used for covering the main planes. The method of preparing this cloth is detailed a little farther along.

The struts, so-called, to continue the analogy with the main planes, are turned sticks of spruce $\frac{3}{8}$ inch in diameter. They are fitted at each end with ferrules of thin $\frac{3}{8}$-inch brass, or steel tubing, driven on tight. Instead of using sockets, the struts are held at each end, simply by a long wood screw driven through the tin and wood of the plane frame and into the strut. These screws also hold the turnbuckles for the truss wires. For trussing purposes, the elevator is regarded as consisting of two sections only, the intermediate struts being disregarded.

The turnbuckles and wire used here and in the other control members may well be of lighter stock than those used in the main planes. Piano wire, No. 18, or $\frac{1}{16}$-inch cable is amply strong. The sheet steel may be about 22 gauge, instead of 16, and the bicycle spokes smaller in proportion. No turnbuckle plates are necessary. The screws running into the struts may be passed directly through the eyes of the turnbuckles, where they would have been attached to the turnbuckle plate. In order to secure a square and neat structure, those struts which have turnbuckles at their ends should be made a trifle shorter than the others.

At each end, the elevator has an **X**-shaped frame of $\frac{1}{4}$-inch steel tubing; at the intersection of the **X**'s are pivots on which the elevator is supported. Each **X** is made of two tubes, bent into a **V** and flattened and brazed together at the points. The ends of the **X**'s are flattened and bent over so that the screws which hold the struts in place may pass through them.

Fig. 19. Curtiss Biplane Ready for Flight

To the front middle strut is attached an extension which acts as a lever for operating the elevator. This is a stick of spruce $\frac{3}{4}$ inch in diameter and 3 feet 3 inches long. At its upper end it has a ferrule of steel tubing, flattened at the end. The lower part of the stick may be fastened to the strut by wrapping the tube with friction tape, or by improvising a couple of sheet steel clamps. The upper end of the stick is braced by a $\frac{1}{4}$-inch steel tube, extending to the top of the rear middle strut, and held by the same screw as the strut. This extension lever is connected to the steering column by a bamboo rod, 1 inch in diameter and about 10 feet long, provided with flattened ferrules of steel tubing at each end. Each ferrule should be held on by a $\frac{1}{8}$-inch stove bolt passing through it.

Front and Rear Outrigger Frames. Both the front elevator and the tail and rudder at the rear, are carried, as mentioned above, each on a pair of **A**-shaped frames, similar to one another, except that those in the rear are longer than those in the front. Both are made of spruce of about the same section as used for the struts of the main frame. These pieces may either be full length, or they may be jointed at the intersection of the crosspieces, the ends being clamped in a sheet-steel sleeve, just like that used on the beams of the main frame. In this case, it is advisable to run a $\frac{1}{8}$-inch stove bolt through each of the ends.

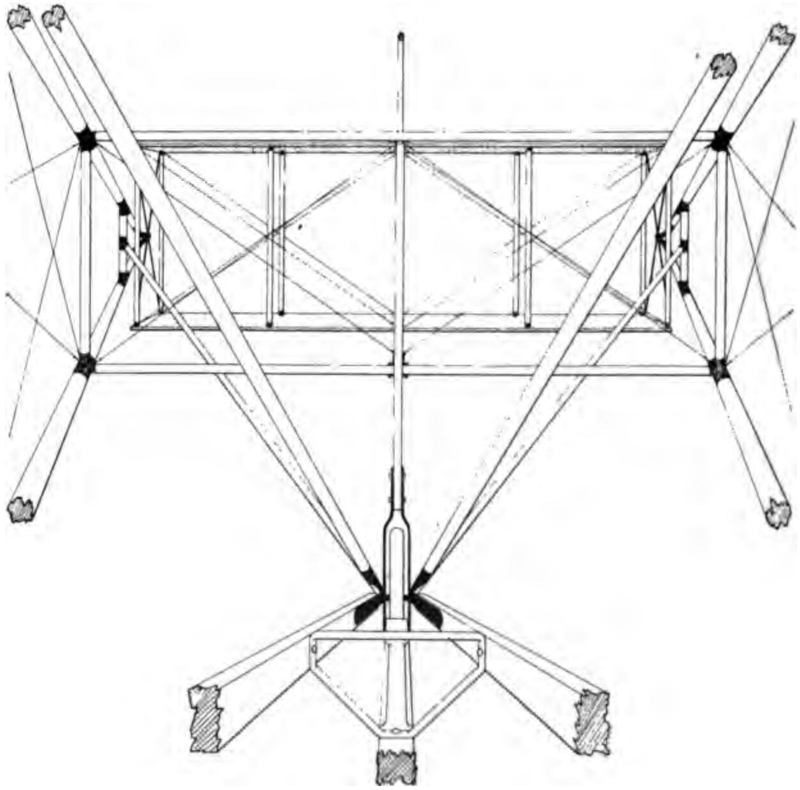

Fig. 20. Details of Outriggers and Front Elevating Planes as Seen from Driver's Seat

The crosspieces of the **A**-frames are spruce of the same section, or a little smaller. At their ends may be used strut sockets like those of the main frame; or, if it is desired to save this expense, they may be fastened by strips of $\frac{1}{16}$-inch steel stock with through bolts.

The front outrigger has, besides the two **A**-frames, a rather complicated arrangement of struts designed to brace the front wheel against the shocks of landing. This arrangement does not appear very plain in a plan or elevation, and may best be understood by reference to the photograph, Fig. 19, and the perspective drawing, Fig. 20. Fig. 20 is a view from the driver's seat. The elevator is seen in front, the **A**-frames at each side, and at the bottom the two diagonal beams to the engine bed and the skid.

Reference to this drawing will show the two diagonals run from the front wheel up and back to the top of the main frame, and two more from the wheel forward to the short crosspieces near the apexes of the **A**-frame: there is also a vertical strut which intersects two horizontal pieces running between the ends of the longer crosspieces of the **A**-frames. Altogether, there are five attachments on each side of the front wheel, through which the axle bolt must pass, viz, the connections to the skid, to one of the diagonals to the engine bed, to one of the rear diagonals, to one of the front diagonals, and to one side of the fork carrying the vertical strut. Of these the skid attachments should be on the inside closest to the wheel, and the engine bed diagonals next.

The four additional diagonals running to the front wheel may be spruce of the same section used in the **A**-frames, or turned one inch round. At each end they have flattened ferrules of steel tubing. The beams of the **A**-frames have similar ferrules at the ends where they attach to the main frames. These attachments should be made on the socket bolts of the struts on either side of the middle 6-foot section and on the outer side of the main beams—not between the beam and the socket itself.

It is possible, of course, to make all the **A**-frames and diagonal braces of bamboo, if desired, the qualities of this material already having been referred to. Bamboo rods for this purpose should be between 1 and 1¼ inches in diameter. Where ferrules are fitted on the ends, the hole of the bamboo should be plugged with wood glued in place.

Generally, in the construction of the outrigger frames, the builder can use his own discretion to a considerable extent. There are innumerable details which can be varied—far too many to consider even a part of the possibilities in this connection. If the builder runs across any detail which he does not see mentioned here, he may safely assume that any workmanlike job will suffice. Often, the method may be adapted to the materials on hand. The diagonal wires from the crosspieces of the A-frames to the struts should be crossed.

Rudder and Tail Construction. The frame for the rudder and tail are constructed in much the same way as those for the elevator, Fig. 18. Spruce sticks 1 by ½ inch are used throughout, except for the piece at the back edge of the rudder and the long middle piece across the tail; these should be 1½ by ½ inch. This long middle piece of the tail is laid across on top of the rest of the framework. When the cloth is put on, this makes the upper surface slightly convex while the lower surface remains flat. The ends of this piece should be reinforced with sheet steel, fairly heavy and drilled for ¼-inch bolts, attaching the tail to the A-frames.

The rudder is hung from two posts extending above and below the tail. These posts may be set in cast aluminum sockets, such as may be obtained from any supply house for 20 cents apiece. The posts need not be more than ¾ inch in diameter. At their outer ends, they should have ferrules of steel tubing, and the turnbuckles or other attachments for the truss wires should be attached by a wood screw running into the end of each. From these posts the rudder may be hung on any light hinges the builder may find convenient, or on hinges improvised from screw eyes or eye bolts, with a bolt passing through the eyes of each.

In steering, the rudder is controlled by a steering wheel carried on a hinged post in front of the pilot. This post should be ash about 1 by 1¼ inches. It hinges at the bottom on a steel tube of ½-inch diameter which passes through it and is supported at the ends on diagonal beams to the engine bed. Two diagonals of lighter tubing may be put in to hold the posts centered between the two beams.

The post is, of course, upright, and the hub of the wheel is horizontal. The wheel may be conveniently mounted on a piece of tubing of the same size as the hub hole, run through the post and held by a comparatively small bolt, which passes through it and has a big washer on either end. The wheel is preferably of the motor-boat variety with a groove around the rim for the steering cable.

The rear edge of the tail should be about 1 inch lower than the front. To make the rudder post stand approximately vertical, wedge-shaped pieces of wood may be set under the sockets.

The steering connections should be of flexible cables of steel such as are made for this purpose. There should be a double pulley on the post just under the wheel, and the cables should be led off the post just at the hinge at the bottom, so that swinging the post will not affect them. The cable is then carried under the lower main plane and out the lower beams of the A-frames. It is attached to the rudder at the back edge; snap hooks should be used for easy disconnection in packing. Perhaps the best way of guiding the cable, instead of using pulleys, is to run it through short pieces of tubing lashed to the beams with friction tape. The tubing can be bent without flattening by first filling it with melted lead, which, after the bending, can be melted out again.

Ailerons for Lateral Stability. The framework of the ailerons is made in the same way as that for the elevator, tail, and rudder, Fig. 18. The pieces around the edges should be $1\frac{1}{2}$ by $\frac{1}{2}$ inch, as also the long strip laid over the top of the ribs. The ribs should be $\frac{1}{2}$ by $\frac{3}{4}$ inch. Each aileron has two holes, one for the strut to pass through, and the other for the diagonal truss wires at their intersection. The back edge also has a notch in it to clear the fore and aft wires. Each aileron is hung on four strips of soft steel about $\frac{1}{2}$ by $\frac{1}{16}$ inch, twisted so that one end is at right angles to the other. These are arranged one on each side of the strut which passes through the aileron, and one at each end. Bolts through the struts carry three of them and the outer one is trussed by wires to each end of the outer strut.

A frame of $\frac{1}{4}$-inch steel tubing fits around the aviator's shoulders and is hinged to the seat, so that he can move it by leaning from one side to the other. This is connected by flexible cable to the rear edges of the ailerons, so that when the aviator leans to the left, he will raise the left and lower the right aileron. The upper edges of the ailerons are directly connected to each other by a cable running along the upper front beam, so that they must always move together.

Covering of the Planes. Mention has already been made of the fact, in the general description of the machine, that light sail cloth, as employed on the Wright machines, may be used for the planes or wings. As a matter of fact, many different materials may be successfully employed, the selection depending upon the builder himself and his financial resources. About 55 square yards of material will be required, and in comparing prices always compare the width as this may vary from 28 to 55 inches. Rubberized silk which is used on the standard Curtiss machines is the most expensive covering, its cost running up to something like two hundred dollars. There are also several good aero fabrics on the market which sell at 60 cents a square yard, as well as a number of brands of varnish for the cloth—most of them, however, quite expensive. The most economical method is to employ a strong linen cloth coated with shellac, which will be found very satisfactory.

The covering of the frames with the cloth may well be postponed until after the engine has been installed and tested, thus avoiding the splashing of oil and dirt which the fabric is apt to receive during this operation. The wire to which the cloth is laced, must be strung along the rear ends of the ribs of each plane. The wires pass through holes in the ends of the small ribs and are attached to the main ribs with turnbuckles. At the ends of the planes the main ribs must be braced against the pull of the wire by a piece of ¼-inch tubing running from the end of the rib diagonally up to the rear beam. Both turnbuckles and tube are fastened with one wood screw running into the end of the rib.

The cloth should be cut to fit the panels between the main ribs and hemmed up, allowing at least an inch in each direction for stretch. Small eyelets should be put along the sides and rear edges an inch apart for the lacing. At the front edge, the cloth is tacked directly to the beam, the edge being taken well under and around to the back. Strong fish line is good material for the lacing.

After the cloth is laced on, it must be tacked down to the small ribs. For this purpose, use upholstery tacks as they have big cup-shaped heads which grip the cloth and do not tear out. As an extra precaution a strip of heavy tape must be run over each rib under the tack heads. All the control members are covered on both sides, the edges being folded under and held by tacks.

Making the Propeller. If the completed biplane is to fly properly and also have sufficient speed to make it safe, considerable care must be devoted to the design and making of the propeller. Every aeroplane has a safe speed, usually referred to in technical parlance as its *critical speed.* In the case of the Curtiss biplane under consideration, this speed is about 40 miles an hour.

By speeding up the motor considerably, it may be able to make 42 to 43 miles an hour in a calm, such a condition representing the only true measure of an aeroplane's ability in this direction, while on the other hand, it would not be safe to let its speed with relation to the wind (not to the ground) fall much below 35 miles an hour. At any slower rate of travel, its dynamic stability would be precarious and the machine would be likely to dive to the ground unexpectedly. The reasons for this have been explained more in detail under the heading of "The Internal Work of the Wind."

The necessity of making the propeller need not discourage the ambitious builder—if he can spare the time to do it right, it will be excellent experience. If not, propellers designed for driving a machine of this size can be purchased ready to mount from any one of quite a number of manufacturers. But as the outlay required will be at least $50, doubtless most experimenters will prefer to undertake this part of the work as well as that of building the framework and main cell, particularly as more than 90 per cent of the sum mentioned is represented by labor. The cost of the material required is insignificant by comparison.

True-Screw Design. First it will be necessary to design the propeller to meet the requirements of the biplane itself. As this is a matter that has already been gone into in considerable detail under the appropriate heading, no further explanation of propeller characteristics or of the technical terms employed, should be needed here. We will assume that the biplane is to have a speed of 40 miles per hour in still air with the motor running at 1,200 r. p. m. With this data, it will not be difficult to calculate the correct pitch of the propeller to give that result. Thus

$$\frac{40\times5280\times100}{60\times1200\times\ 85}=3.45$$

or in round numbers a pitch of 3½ feet. 40 (the speed in miles per hour) times 5,280 (feet per mile) divided by 60 (minutes in an hour) gives the speed of the aeroplane in feet per minute. Dividing this by 1,200 (revolutions per minute) gives the number of feet the aeroplane is to advance per revolution of the propeller. The "$\frac{100}{85}$" part of the equation represents the efficiency of the propeller which can safely be figured on, *i. e.*, 85 per cent, or an allowance for slip of 15 per cent. Forty miles an hour is the maximum speed to be expected, while the r. p. m. rate of the engine should be that at which it operates to the best advantage.

The merits of the *true-screw* and *variable-pitch* propellers have already been dwelt upon. The former is not only more simple to build, but experience has shown that, as generally employed, it gives better efficiency. Hence, the propeller under consideration will be of the true-screw type. Its pitch has already been calculated as 3½ feet. For a machine of this size and power, it should be 6 feet in diameter. Having worked out the pitch and decided upon the diameter, the next and most important thing is to calculate the pitch angle. It will be evident that no two points on the blade will travel through the air at the same speed. Obviously, a point near the tip of the propeller moves faster than one near the hub, just as in rounding a curve, the outer wheel of an automobile has to travel faster than the inner, because it has to travel farther to cover the same ground. For instance, taking the dimensions of the propeller in question it will be seen that its tips will be traveling through the air at close to 4.3 miles per minute, that is,

$$\frac{6\times\pi\times 1200}{5280}=4.28$$

in which 6, the diameter of the propeller in feet, times π gives the circumference of the circle which is traveled by the blade tips 1,200 times per minute; this divided by the number of feet per mile gives the miles per minute covered. On the other hand, a point on the blade but 6 inches from the hub will turn at only approximately 3,500 feet per minute. Therefore, if every part of the blade is to advance through the air equally, the inner part must be set at a greater angle than the outer part. Each part of the blade must be set at such an angle that at each revolution it will move forward through the air a distance equal to the pitch. This is known as the pitch angle. The pitch divided by the circumference of the circle described by any part of the blade, will give a quantity known as the *tangent* of an angle for that particular part. The angle corresponding to that tangent may most easily be found by referring to a book of trigonometric tables.

For example, take that part of the blade of a 3½-foot pitch pro-

TABLE II
Propeller Blade Data

Radius in Inches	Tangent	Pitch Angle	Add	Final Angle
6	1.1141	48° 5′	....	48°
9	.7427	36° 36′	....	37°
12	.5571	29° 7′	3° 13′	32° 20′
15	.4457	24° 1′	3° 9′	27° 10′
18	.3719	20° 24′	3° 6′	23° 30′
21	.3183	17° 40′	3°	20° 40′
24	.2785	15° 40′	2° 50′	18° 30′
27	.2476	13° 54′	2° 46′	16° 40′
30	.2228	12° 40′	2° 45′	15° 25′
33	.2025	11° 27′	2° 43′	14° 10′

peller which is 6 inches from the center of the hub. Then

$$\frac{3.5\times 12}{6\times 2\pi}=1.1141 \text{ tangent of 48 degrees 5 minutes}$$

in which 3.5×12 reduces the pitch to inches, while $6\times 2\pi$ is the circumference of the circle described by the point 6 inches from the hub. However, in order to give the propeller blade a proper hold on the air, it must be set at a greater angle than these figures would indicate. That is, it must be given an angle of incidence similar to that given to every one of the supporting planes of the machine. This additional angle ranges from 2 degrees 30 minutes, to 4 degrees, depending upon the speed at which the particular part of the blade travels; the greater the speed, the less the angle. This does not apply to that part of the blade near the hub as the latter is depended upon solely for strength and is not expected to add to the effective thrust of the propeller.

Table II shows the complete set of figures for a blade of 3½-foot pitch, the angles being worked out for sections of the blade 3 inches apart.

These angles are employed in Fig. 21, which shows one blade of the propeller and its cross sections.

It should be understood that these calculations apply only to the type of propeller known as the *true screw*, as distinguished from the *variable pitch*. The design of the latter is a matter of personal skill and experience in its making which is hardly capable of

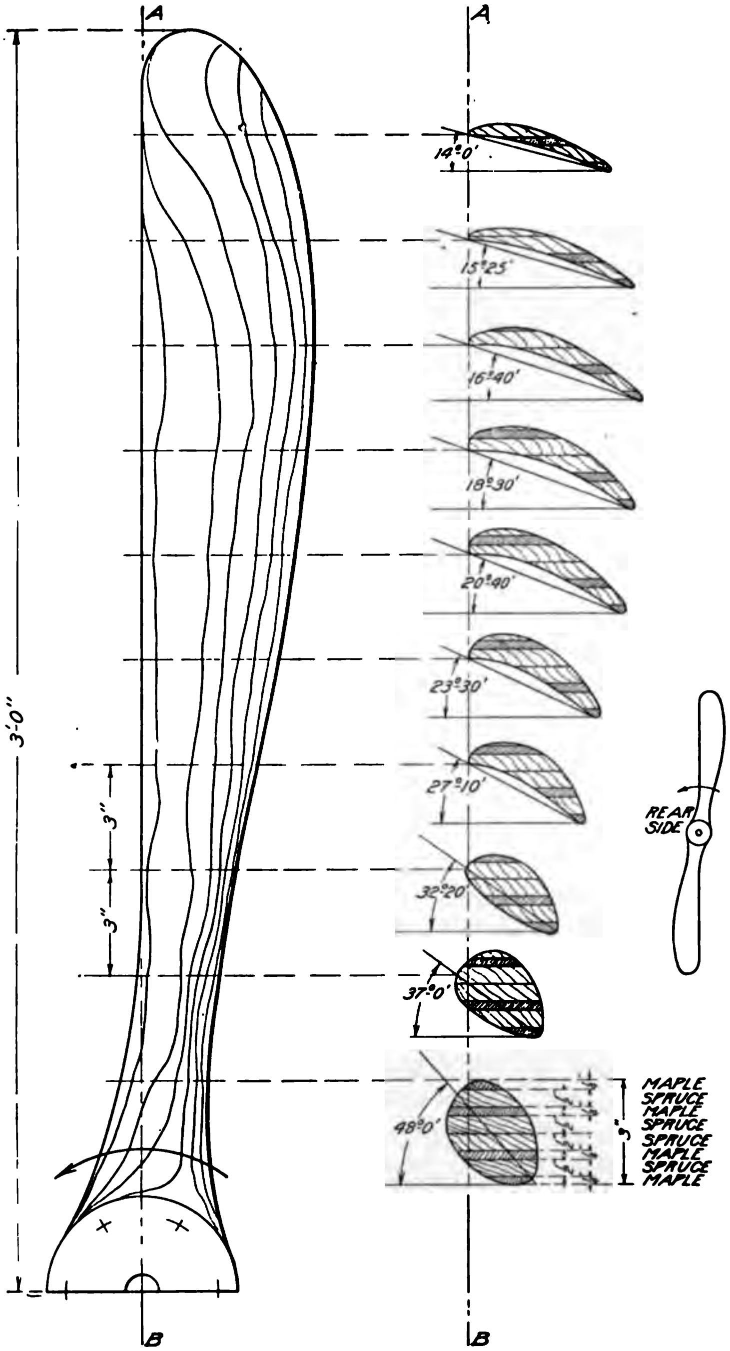

Fig. 21. Details of Propeller Construction, Curtiss Biplane

expression in any mathematical formula. There are said to be only about three men in this country who know how to make a proper variable-pitch propeller, and it naturally is without advantage when made otherwise.

Shaping the Blades. Like the ribs, the propeller is made up of a number of laminations of boards finished true and securely glued, afterward being cut to the proper shape, though this process, of course, involves far more skill than in the former case. Spruce is the strongest wood for its weight, but it is soft and cracks easily. Maple, on the other hand, is tough and hard, so that it will be an advantage to alternate the layers of these woods with an extra maple board, in order to make both outside strips of the harder wood, so as to form a good backing for the steel flanges at the hub, the rear layer extending the full length of the thin rear edges of the blades. Other woods may be employed and frequently are used by propeller manufacturers, such as mahogany (not the grained wood used for furniture, but a cheaper grade which is much stronger), walnut, alternate spruce and whitewood, and others.

The boards should be selected with the greatest care so as to insure their being perfectly *clear, i.e.,* absolutely free of knots, cross-grained streaks, or similar flaws, which would impair their strength and render them difficult to work smoothly. They should measure 6 inches wide by 6 feet 1 inch in length. Their surfaces must be finished perfectly true, so that they will come together uniformly all over the area on which they bear on one another, and the various pieces must be glued together with the most painstaking care. Have the glue hot, so that it will spread evenly, and see that it is of a uniform consistency, in order that it may be smoothly applied to every bit of the surface. They must then be clamped together under as much pressure as it is possible to apply to them with the means at hand, the rib press already described in detail forming an excellent tool for this purpose. Tighten up the nuts evenly a little at a time, avoiding the application of excessive or uneven pressure at one point, continuing the gradual tightening up process until it can not be carried any farther. This is to prevent the boards from assuming a curve in drying fast. Allow at least twenty-four hours for drying, during which period the laminated block should be kept in a cool, dry place at as even a temperature as possible.

Before undertaking the remainder of the work, all of which must be carried out by hand, with the exception of cutting the block to the outline of the propeller, which may be done with a band saw, a set of templates or gauges should be made from the drawings. These will be necessary as guides for finishing the propeller acurately. Draw the sections out full size on sheets of cardboard or tin and cut out along the curves, finally dividing each sheet into two parts, one for the upper side and one for the lower. Care must be taken to get the sides of the template square, and when they are used, the propeller should be laid on a perfectly true and flat block. Each template should be marked as it is finished, to indicate what part of the blade it is a gauge for. The work of cutting the laminated block down to the lines represented by the templates is carried out with the aid of the plane, spoke shave, and gouge. After the first *roughing out* to approximate the curvature of the finished propeller is completed, the cuts taken should be very fine, as it will be an easy matter to go too deep, thus spoiling the block and necessitating a new start with fresh material. For finishing, pieces of broken glass are employed to scrape the wood to a smooth surface, followed by coarse and finally by fine sandpaper.

Mounting. The hub should be of the same diameter as the flange on the engine crank shaft to which the flywheel was bolted, and should have its bolt holes drilled to correspond. To strengthen the hub, light steel plates of the same diameter are screwed to it, front and back, and the bolt holes drilled right through the metal and wood. This method of fastening is recommended where it is possible to substitute the propeller for the flywheel formerly on the engine, it being common practice to omit the use of the flywheel altogether. The writer does not recommend this, however, as the advantages of smoother running and more reliable operation gained by the use of a flywheel in addition to the propeller far more than offset any disadvantage represented by its weight. It will be noted that the Wright motors have always been equipped with a flywheel of ample size and weight and this is undoubtedly responsible, in some measure at least, for the fact that the Wright biplanes fly with considerably less power than is ordinarily employed for machines of the same size. If the motor selected be equipped with an unusually heavy flywheel, and particularly where the wheel is of comparatively small diameter, making it less effective as a balancer, it may be replaced with one of lighter weight and larger diameter. It may be possible to attach it by keying to the forward end of the crank shaft, thus leaving the flange from which the flywheel was taken free for mounting the propeller. An ordinary belt pulley will serve excellently as the new flywheel, as most of its weight is centered in its rim, but as the common cast-iron belt pulley of commerce is seldom intended to run at any such speed as that of an automobile motor, it should be examined carefully for flaws. Otherwise, there will be danger of its bursting with disastrous results under the influence of centrifugal force. Its diameter should not exceed 16 inches in order to keep its peripheral speed within reasonable limits. Where the mounting of the motor permits of its use, a wood pulley 18 to 20 inches in diameter with a steel band about $\frac{1}{8}$- to $\frac{1}{4}$-inch thick, shrunk on its periphery, may be employed. Most builders will ridicule the idea of a flywheel other than the propeller itself. "You do not need it; so why carry the extra weight?" will be their query. It is not absolutely necessary, but it is an advantage.

In case the flywheel of the engine selected is keyed to the crank shaft, or in case it is not possible to mount both the flywheel and the propeller on different ends of the crank shaft, some other expedient rather than that of bolting to the flange must be adopted. In such a case, the original flywheel, where practical to retain it, may be drilled and tapped and the propeller attached directly to it. Where the flywheel can not be kept, it will usually be found practical to cut off its rim and bolt the propeller either to the web or spokes, or to the flywheel hub, if it be cut down to the latter.

The drawing, Fig. 21, shows the rear or concave side of the propeller. From the viewpoint of a man standing in its wind and facing forward, it turns to the left, or anti-clockwise. On many of the propellers now on the market, the curved edge is designed to go first. This type may have greater advantages over that described, but the straight front edge propeller is easier for the amateur to make.

Mounting the Engine. Having completed the propeller, the next step is the mounting of the engine. Reference to the types available to the amateur aeroplane builder has already been made. There are a number of motors now on the market that have been designed specially for this purpose and not a few of them are of considerable merit. Their cost ranges from about $250 up to $2,500, but it may be possible to pick up a comparatively light-weight automobile motor second hand which will serve all purposes and which will cost far less than the cheapest aeronautic motor on the market. It must be capable of developing 30 actual horse-power at 1,000 to 1,200 r. p. m. and must not exceed 400 pounds complete with all accessories, such as the radiator and piping, magneto, water, oil, etc. Considerable weight may be saved on an automobile motor by removing the exhaust manifold and substituting a lighter flywheel for the one originally on the engine—or omitting it altogether, as just mentioned. A light-weight aeronautic radiator should be used in preference to the usual automobile radiator.

When placing the engine in position on the ash beams forming its bed or support, it must be borne in mind that the complete machine, with the operator in the aviator's seat, is designed to balance on a point about 1½ feet back of the front edge of the main planes. As the operator and the motor represent much the larger part of the total weight, the balance may easily be regulated by moving them slightly forward or backward, as may be required. It will be necessary, of course, to place the engine far enough back in any case to permit the propeller blades to clear the planes. The actual installation of the engine itself will be an easy matter for anyone who has had any experience in either automobile or marine gasoline motor work. It is designed to be bolted to the two engine beams in the same manner as on the side members of the frame of an automobile, or the engine bed in a boat. Just in front of the engine is the best place for the gasoline tank, which should be cylindrical with tapering ends, to cut down its wind resistance. If the designer is not anxious to carry out points as fine as this, a light copper cylindrical tank may be purchased from stock. It should hold at least ten gallons of gasoline. In front of the tank is the radiator.

Controls. The controls may be located to conform to the builder's own ideas of accessibility and convenience. Usually the switch is placed on the steering column, and it may be of the ordinary *knife* variety, or one of the special switches made for this purpose, as taste may dictate. The throttle control and spark advance may either be in the form of pedals, working against springs, or of small levers working on a notched sector, at the side of the seat. The complete control, levers, and sector may be purchased ready to mount whenever desired, as they are made in this form for both automobile and marine work. This likewise applies to the wheel, which it would not pay the amateur to attempt to make.

Another pedal should work a brake on the front wheel, the brake shoe consisting of a strip of sheet steel, fastened at one end to the fore part of the skid and pressed against the wheel by a bamboo rod directly connected with the brake pedal. An emergency brake can also be made by loosely bolting a stout bar of steel on the skid near its rear end; one end of this bar is connected to a lever near the seat, so that when this lever is pulled back the other end of the bar tends to dig into the ground. As making a landing is one of the most difficult feats for the amateur aviator to master and sufficient space for a long run after alighting is not always available, these brakes will be found a very important feature of the machine.

Fig. 22. Method of Starting the Engine of an Aeroplane

The engine is started by swinging the propeller, and this is an operation requiring far more caution than cranking an automobile motor. Both hands should be placed on the same blade, Fig. 22, and the latter should always be pulled downward—never upward.

With the switch off, first turn the propeller over several times to fill the cylinders with gas, leaving it just ahead of dead center of one of the cylinders, and with one blade extending upward and to the left at a 45-degree angle. After closing the switch, take the left blade with both hands and swing it downward sharply, getting out of the way of the following blade as quickly as possible.

Tests. The first thing to be done after the propeller is finished and mounted on the engine is to test the combination, or power plant of the biplane, for speed and thrust, or pulling power. From these two quantities it will be easy to figure the power that the engine is delivering. The only instruments necessary are a spring balance reading to 300 pounds or over; a revolution counter, such as may be procured at any machinist's supply house for a dollar or two; and a watch. One end of the spring balance is fastened to the front end of the skid and the other to a heavy stake firmly driven in the ground a few feet back. The wheels of the biplane should be set on smooth boards so that they will not offer any resistance to the forward thrust. When the engine is started the spring balance will give a direct reading of the pull of the propeller.

With one observer noting the thrust, another should check the number of revolutions the engine is turning per minute. To do this, a small hole should previously have been countersunk in the hub of the propeller to receive the conical rubber tip of the revolution counter. The observer stands behind the propeller, watch in one hand and revolution counter in the other. At the beginning of the minute period, the counter is pressed firmly against the hub, and quickly withdrawn at the end of the minute. A stop watch is naturally an advantage for the purpose. The horse-power is figured as follows, assuming, for example, a thrust of 250 pounds at 1,200 r. p. m.

$$\frac{250 \times 1200 \times 3.5 \times 100}{33.000 \times 85} = 37 \text{ h. p.}$$

As before, the "$\frac{100}{85}$" allows for the slip and represents the efficiency of the propeller; 33,000 is the number of foot pounds per minute or the equivalent of one horse-power, and 3.5 is the pitch of the propeller.

Assembling the Biplane. Assembling the machine complete requires more space than is available in the average workshop.

However, it is possible to assemble the sections of the planes in a comparatively small room, carrying the work far enough to make sure that everything will go together properly when the time comes for complete assembly at the testing ground. In this case, it is preferable to assemble the end sections first, standing them away when complete to make room for the central section, on which the running gear and outriggers are to be built up.

The builder will have decided by this time whether he will make his machine on the regular plan, with one main rib between each section, or on the quick-detachable plan, which has two main ribs on either side of the central section, as previously explained.

It is desirable to be able to assemble two sections at once and this should be possible anywhere as it requires a space only about 6 by 13 feet. Two wood 2×4's, about 12 feet long, should be nailed down on the blocks on the floor; make these level and parallel to each other at a distance of 3 feet 6 inches on centers, one being 3 inches higher than the other. Strips of wood should be nailed on them, so as to hold the main beams of the frame in place while assembling.

The two front and two rear beam sections are laid in place and joined with the sheet-steel sleeves, the flanges of the sleeves on the inner side of the beams. Then through the sleeves in the front beams, which are, of course, those on the higher bed, drill the holes for the strut socket bolts (¼ inch). The holes for the outer ones go through the projecting ends of the beams; those for the inner ones are half in each of the two abutting beams. At the end where the central section joins on, a short length of wood of the same section may be inserted in the sleeve while drilling the hole. An assistant should hold the beams firmly together while the holes are being drilled.

Now lay in place the three main ribs belonging to the two sections under construction and fasten them at the front ends by putting in place the strut sockets for which the holes have been drilled, with a turnbuckle plate under each socket, Fig. 16. The strut socket bolt passes through the main rib and the beam. The bed on which the assembling is being done, should be cut when sufficiently under the joints to leave room for the projecting bolt ends. Set the ribs square with the front beams, then arrange the rear beams so that their joints come exactly under the ribs; clamp the ribs down and drill a true, vertical hole through the rib beam, holding the two sections of the beam together as before. Then put the rear strut sockets in place, using the angle washers previously described, above and below the rib.

When the quick-detachable plan is followed, the ribs at the inner ends of the double section, where they join the central section, should be bolted on an inch from the ends of the beam, using ¼-inch stove bolts instead of the socket bolts. The sleeves should be slotted, so that they can slide off without removing these bolts, as the sleeves and ribs which occupy the position over the joints of the beams, belong to the central section.

The sections should now be strung up with the diagonal truss wires which will make them rigid enough to stand handling. The wires are attached at each end to the flange bolts of the sleeves. Either one or two turnbuckles may be used on each wire, as already explained; if but one turnbuckle be used, the other end of the wire may be conveniently attached to a strip of sheet steel bent double and drilled for the bolt, like the sheet-steel slip of a turnbuckle. The attachment, of whatever nature, should be put between the end and the flange of the sleeve, not between the two flanges.

Three or four ribs can be used on each section; four are preferable on sections of full 6-foot length. They are, of course, evenly spaced on centers. At the front ends, they are attached to the beam by wood screws through their flattened ferrules. The attachment to the rear beam is made with a slip of sheet steel measuring ½ by 3 inches, bent over the rib and fastened to the beam at each side with a wood screw. A long wire nail is driven through the rib itself on the beam.

Four double sections should be built up in this manner, the right and left upper and the right and left lower sections. Uppers and lowers are alike except for the inversion of the sockets in the upper sections. Rights and lefts differ in that the outer beams are long enough to fill up the sleeves, not leaving room for another beam to join on.

Inserting the struts in their sockets between the upper and lower sections of the same side will now form either of the two sides of the machine complete. Care should be taken to get the rear struts the proper length with respect to the front ones to bring the upper and lower planes parallel. The distance from the top of the lower front beam to the top of the upper front beam should be the same as the distance between the rows of bracing holes in the upper and lower main ribs just above and below the rear struts—about 4 feet 6 inches. It should hardly be necessary to mention that the thick edges of the struts come to the front—they are fish-shaped and a fish is thicker at the head than at the tail.

The truss wires may now be strung on in each square of the struts, beams, and main ribs, using turnbuckles as previously described. The wires should be taut enough to sing a low note when plucked between the thumb and forefinger. If the construction is carried out properly, the framework will stand square and true with an even tension on all the wires. It is permissible for the struts to slant backward a little as seen from the side, but all should be perfectly in line.

For adjusting the turnbuckles, the builder should make for himself a handy little tool usually termed a nipple wrench. It is simply a strip of steel $1\frac{1}{2}$ by $\frac{1}{2}$ by $\frac{3}{32}$ inches, with a notch cut in the middle of the long sides to fit the flattened ends of the turnbuckle nipples. This is much handier than the pliers and does not burr up the nipples.

It has been assumed in this description of the assembling that the builder is working in a limited space; if, on the contrary, he has room enough to set up the whole frame at once, the work will be much simpler. In this case, the construction bed should be 30 feet long. First build up the upper plane complete, standing it against the wall when finished; then build the lower plane, put the struts in their sockets, and lay on the upper plane complete.

Returning to the plan of assembly by sections, after the side sections or wings of the machine have been completed, the struts may be taken out and the sections laid aside. The middle section, to which the running gear and outriggers will be attached, is now to be built up in the same way. If the builder is following the plan in which there is one main rib between each section, it will be necessary to take off the four inner main ribs from the sections already completed, to be used at the ends of the central section. The plan drawing of the complete machine shows that the ribs of the central section are cut off just back of the rear beam to make room for the propeller. This is necessary in order to set the motor far enough forward to balance the machine properly. The small ribs in this section have the same curve but are cut off 10 inches shorter at their rear ends, and the stumps are smoothed down for ferrules like those for the other small ribs. In the plan which has one main rib between each section, the main rib on each side of the central section must be left full length. In the quick-detachable plan with two main ribs on each side of the central section, the inner ones, which really belong to this section, are cut off short like the small ribs.

In the drawing of the complete machine, the distance between the struts which carry the engine bed is shown as 2 feet. This is only approximate, as the distance must be varied to suit the motor employed. By this time, the builder will have decided what engine he is going to use—or can get—and should drill the holes for the sockets of these struts with due respect to the width of the engine's supporting feet or lugs, remembering that the engine bed beams go on the inside of the struts. In the drawing of the running gear, Fig. 17, the distance between the engine-bed struts has been designated *A*. The distances, *B*, on each side are, of course, approximately $(6'-2A)$, whatever *A* may be.

A FRENCH ARMY CAPTAIN READY FOR A START WITH A MILITARY TYPE BLERIOT MONOPLANE

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BUILDING AND FLYING AN AEROPLANE

PART II

BUILDING A BLERIOT MONOPLANE

As mentioned in connection with the description of its construction, the Curtiss biplane was selected as a standard of this type of aeroplane after which the student could safely pattern for a number of reasons. It is not only remarkably simple in construction, easily built by anyone with moderate facilities and at a slight outlay, but it is likewise the easiest machine to learn to drive. The monoplane is far more *difficult* and *expensive* to build.

The Bleriot may be regarded as the most typical example in this field, in view of its great success and the very large numbers which have been turned out. In fact, the Bleriot monoplane is the product of a factory which would compare favorably with some of the large automobile plants. Its construction requires skillful workmanship both in wood and metal, and a great many special castings, forgings, and stampings are necessary. Although some concerns in this country advertise that they carry these fittings as *stock parts*, they are not always correct in design and, in any case, are expensive. Wherever it is possible to avoid the use of such parts by any expedient, both forms of construction are described, so that the builder may take his choice.

Bleriot monoplanes are made in a number of different models, the principal ones being the 30-horse-power "runabout," Figs. 23 and 24, the 50- and 70-horse-power passenger-carrying machines, and the 50-, 70-, and 100-horse-power racing machines. Of these the first has been chosen as best adapted to the purpose. Its construction is typical of the higher-power monoplanes of the same make, and it is more suitable for the beginner to fly as well as to build. It is employed exclusively by the Bleriot schools.

Motor. The motor regularly employed is the 30-horse-power, three-cylinder Anzani, a two-cylinder type of which is shown in

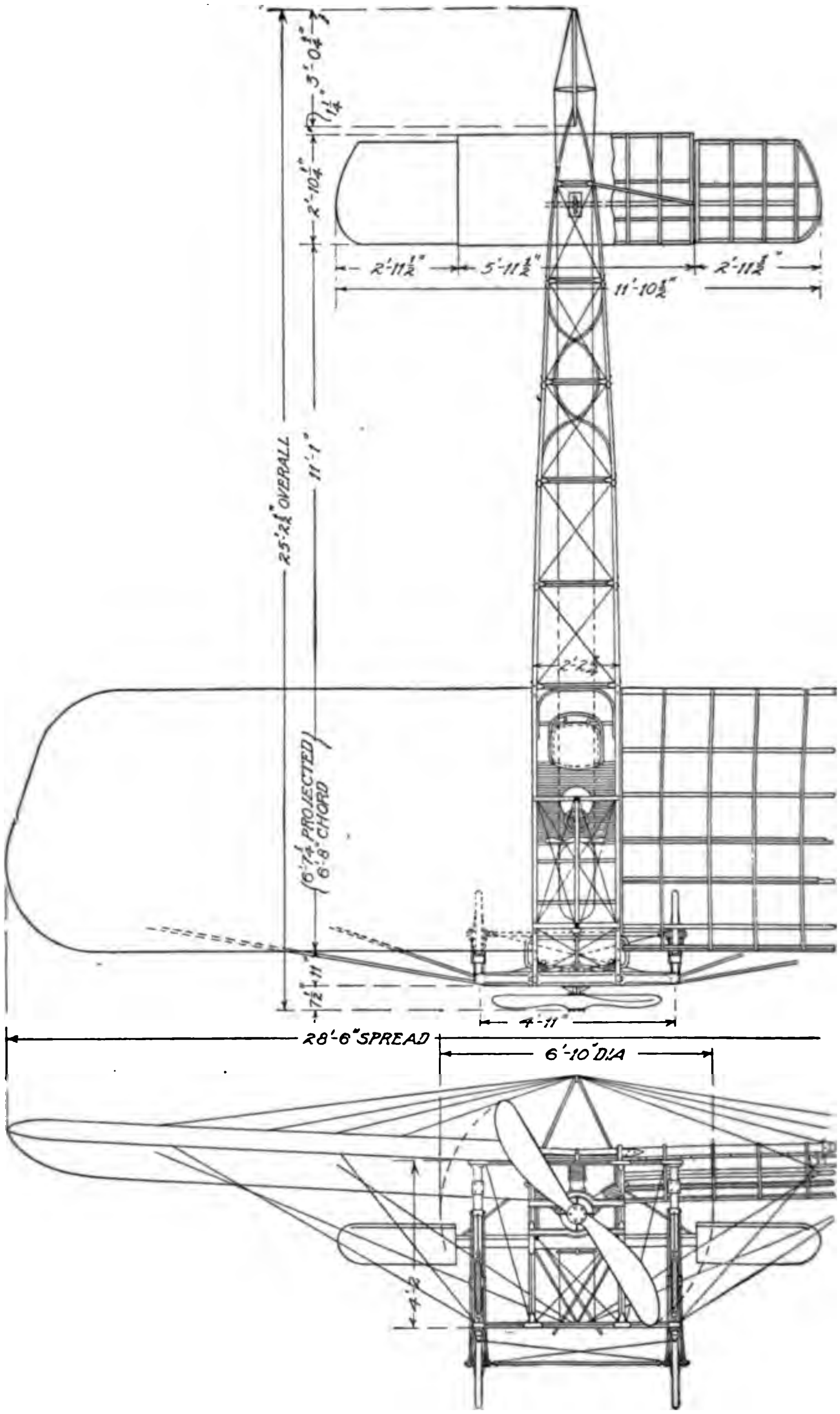

Fig. 23. Details of Bleriot Monoplane

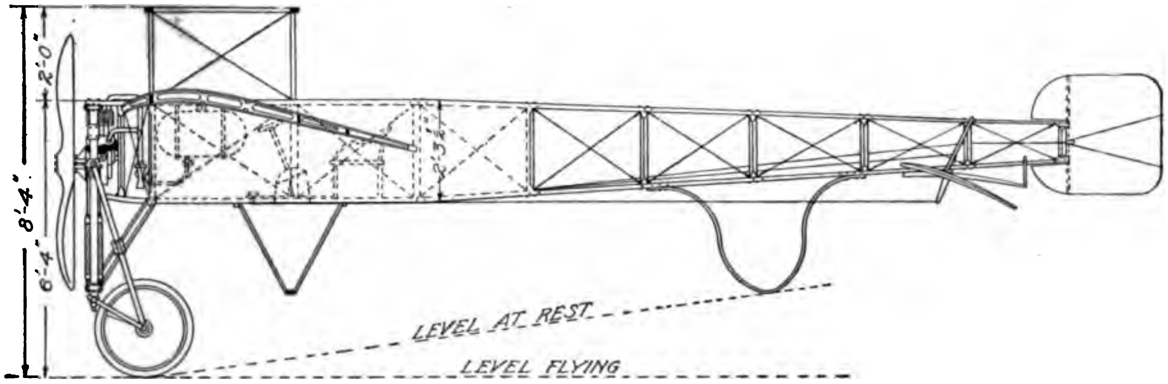

Fig. 24. Side Elevation of Bleriot Monoplane

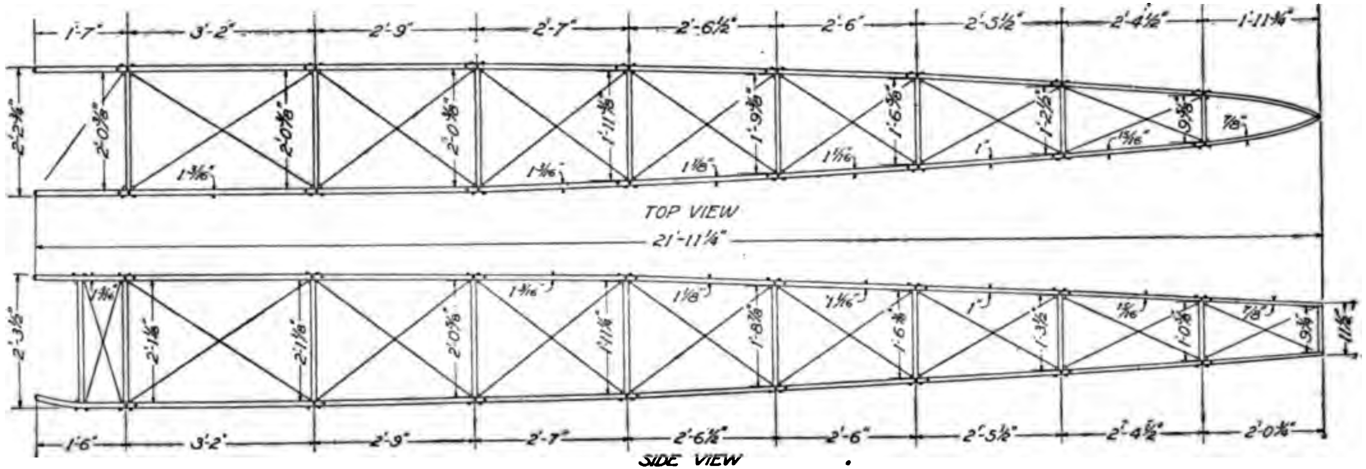

Fig. 25. Top and Side View of Bleriot Fuselage on Which Machine Is Assembled

"Aeronautical Motors," Fig. 40. From the amateur's standpoint, a disadvantage of the Bleriot is the very short space allowed for the installation of the motor. For this reason, the power plant must be fan shaped, like the Anzani; star form, like the Gnome; or of the two-cylinder opposed type. It must likewise be air-cooled, as there is no space available for a radiator.

Fuselage. Like most monoplanes, the Bleriot has a long central body, usually termed "fuselage," to which the wings, running gear, and controls are all attached. A drawing of the fuselage with all dimensions is reproduced in Fig. 25, and as the machine is, to a large extent, built up around this essential, its construction is taken up first. It consists of four long beams united by 35 crosspieces. The beams are of ash, $1\frac{3}{16}$ inches square for the first third of their length and tapering to $\frac{7}{8}$ inch square at the rear ends. Owing to the difficulty of securing good pieces of wood the full length, and also to facilitate packing for shipment, the beams are made in halves, the abutting ends being joined by sleeves of $1\frac{1}{8}$-inch, 20-gauge steel tubing, each held on by two $\frac{1}{8}$-inch bolts. Although the length of the fuselage is 21 feet $11\frac{1}{4}$ inches, the beams must be made of two 11-foot halves to allow for the curve at the rear ends.

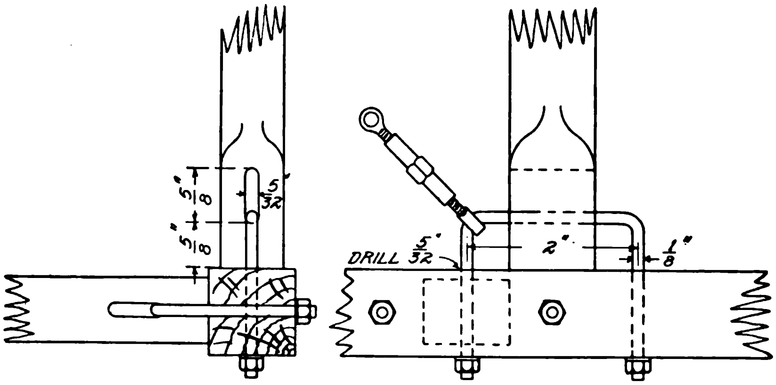

Fig. 26. Details of U-bolt Which Is a Feature of Bleriot Construction

The struts are also of ash, the majority of them being $\frac{7}{8}$ by $1\frac{1}{4}$ inches, and oval in section except for an inch and a half at each end. But the first, second, and third struts (counting from the forward end) on each side, the first and second on the top, and the first strut on the bottom are $1\frac{3}{16}$ inches square, of the same stock as the main beams. Practically all of the struts are joined to the main beams by **U**-bolts, as shown by the detail drawing, Fig. 26, this being one of Louis Bleriot's inventions. The small struts are held by $\frac{1}{8}$-inch bolts and the larger ones by $\frac{3}{16}$-inch bolts. The ends of the struts must be slotted for these bolts, this being done by drilling three holes in a row with a $\frac{5}{32}$- or $\frac{7}{32}$-inch drill, according to whether the slot is for the smaller or larger size bolt. The wood between the holes is cut out with a sharp knife and the slot finished with a coarse, flat file.

All of the **U**-bolts measure 2 inches between the ends. The vertical struts are set 1 inch forward of the corresponding horizontal struts, so that the four holes through the beam at each joint are spaced 1 inch apart, alternately horizontal and vertical. To the projecting angles of the **U**-bolts are attached the diagonal truss wires, which cross all the rectangles of the fuselage, except that in which the driver sits. This trussing should be of 20-gauge piano wire (music-wire gauge) or $\frac{1}{16}$-inch cable, except in the rectangles bounded by the large struts, where it should be 25-gauge piano wire or $\frac{3}{32}$-inch cable. Each wire, of course, should have a turnbuckle. About 100 of these will be required, either of the spoke type or the regular type, with two screw eyes—the latter preferred.

Transverse squares, formed by the two horizontal and two vertical struts at each point, are also trussed with diagonal wires. Although turnbuckles are sometimes omitted on these wires, it takes considerable skill to get accurate adjustments without them. The extreme rear strut to which the rudder is attached, is not fastened in the usual way. It should be cut with tongues at top and bottom, fitting into notches in the ends of the beams, and the whole bound with straps of 20-gauge sheet steel, bolted through the beams with $\frac{1}{8}$-inch bolts.

Continuing forward, the struts have no peculiarity until the upper horizontal one is reached, just behind the driver's seat. As it is impossible to truss the quadrangle forward of this strut, owing to the position of the driver's body, the strut is braced with a **U**-shaped half-round strip of $\frac{1}{2}$ by 1 inch of ash or hickory bolted to the beams at the sides and to the strut at the rear, with two $\frac{1}{8}$-inch bolts at each point. The front side of the strut should be left square where this brace is in contact with it. The brace should be steam bent with the curves on a 9-inch radius, and the half-round side on the inside of the curve.

The vertical struts just forward of the driver's seat carry the inner ends of the rear wing beams. Each beam is attached with a single bolt, giving the necessary freedom to rock up and down in warping the wings. The upper 6 inches of each of these struts fits into a socket designed to reinforce it. In the genuine Bleriot, this socket is an aluminum casting. However, a socket which many would regard as even better can be made from a 7-inch length of 20-gauge 1⅛-inch square tubing. One end of the tube is sawed one inch through the corners; two opposite sides are then bent down at right angles to form flanges, and the other two sides sawed off. A 1- by 3-inch strip of 20-gauge sheet steel, brazed across the top and flanges completes the socket. With a little care, a very creditable socket can be made in this way. Finally, with the strut in place, a ⅜-inch hole is drilled through 4 inches from the top of the socket for the bolt securing the wing beam.

The upper horizontal strut at this point should be arched about six inches to give plenty of elbow room over the steering wheel. The bending should be done in a steam press. The strut should be 1 3/16 inches square, cut sufficiently long to allow for the curve, and fitted at the ends with sockets as described above, but set at an angle by sawing the square tube down further on one side than on the other.

On the two lower beams, is laid a floor of half-inch boards, extending one foot forward and one foot back of the center line of the horizontal strut. This floor may be of spruce, if it is desired to save a little weight, or of ordinary tongue-and-grooved floor boards, fastened to the beams with wood screws or bolts. The horizontal strut under this floor may be omitted, but its presence adds but little weight and completes the trussing. Across the top of the fuselage above the first upper horizontal strut, lies a steel tube which forms the sockets for the inner end of the front wing beams. This tube is 1¾ inches diameter, 18 gauge, and 26¾ inches long. It is held fast by two steel straps, 16 gauge and 1 inch wide, clamped down by the nuts of the vertical strut U-bolts. The center of the tube is, therefore, in line with the center of the vertical struts, not the horizontal ones. The U-bolts which make this attachment are, of course, the 5/16-inch size, and one inch longer on each end than usual. To make a neat job, the tube may be seated in wood blocks, suitably shaped, but these must not raise it more than a small fraction of an inch above the top of the fuselage, as this would increase the angle of incidence of the wings.

The first vertical struts on each side are extras, without corresponding horizontal ones; they serve only to support the engine. When the Gnome motor is used, its central shaft is carried at the centers of two **X**-shaped, pressed-steel frames, one on the front side, flush with the end of the fuselage and one on the rear.

Truss Frame Built on Fuselage. In connection with the fuselage may be considered the overhead truss frame and the warping frame. The former consists of two inverted **V**'s of 20-gauge, 1- by $\frac{3}{8}$-inch oval tubing, joined at their apexes by a 20-gauge, $\frac{3}{4}$-inch tube. Each **V** is formed of a single piece of the oval tubing about 5 feet long. The flattened ends of the horizontal tube are fastened by a bolt in the angles of the **V**'s. The center of the horizontal tube should be 2 feet above the top of the fuselage. The flattened lower ends of the rear **V** should be riveted and brazed to strips of 18-gauge steel, which will fit over the bolts attaching the vertical fuselage struts at this point. The legs of the front **V** should be slightly shorter, as they rest on top of the wing socket tube. Each should be held down by a single $\frac{3}{16}$-inch bolt, passing through the upper wall of the tube and its retaining strap; these bolts also serve the purpose of preventing the tube from sliding out from under the strap. Each side of the frame is now braced by diagonal wires (No. 20 piano wire, or $\frac{1}{16}$-inch cable) with turnbuckles.

At the upper corners of this frame are attached the wires which truss the upper sides of the wings. The front wires are simply fastened under the head and nut of the bolt which holds the frame together at this corner. The attachment of the rear wires, however, is more complex, as these wires must run over pulleys to allow for the rocking of the rear wing beams when the wings are warped. To provide a suitable place for the pulleys, the angle of the rear **V** is enclosed by two plates of 20-gauge sheet steel, one on the front and one on the rear, forming a triangular box 1 inch thick fore and aft, and about 2 inches on each side, only the bottom side being open. These plates are clamped together by a $\frac{3}{16}$-inch steel bolt, on which are mounted the pulleys. There should be sufficient clearance for pulleys 1 inch in diameter. The wires running over these pulleys must then pass through holes drilled in the tube. The holes should not be drilled until the wings are on, when the proper angle for them can be seen. The cutting and bending of the steel plates is a matter of some difficulty, and should not be done until the frame is otherwise assembled, so that paper patterns can be cut for them. They should have flanges bent around the tube, secured by the bolts which hold the frame together, to keep them from slipping off.

The oval tubing is used in the vertical parts of this frame, principally to reduce the wind resistance, being placed with the narrow side to the front. However, if this tubing be difficult to obtain, or if price is a consideration, no harm will be done by using $\frac{3}{4}$-inch round tubing. Beneath the floor of the driver's cockpit in the fuselage is the warping frame, the support for the wires which truss the rear wing beams and also control the warping.

This frame is built up of four $\frac{3}{4}$-inch, 20-gauge steel tubes, each about 3 feet long, forming an inverted, 4-sided pyramid. The front and back pairs of tubes are fastened to the lower fuselage beams with $\frac{3}{16}$-inch bolts at points 15 inches front and back of the horizontal strut. At their lower ends the tubes are joined by a fixture which carries the pulleys for the warping wires and the lever by which the pulleys are turned. In the genuine Bleriot, this fixture is a special casting. However, a very neat connection can be made with a piece of $\frac{1}{16}$-inch steel stock, $1\frac{1}{4}$ by 6 inches, bent into a U-shape with the legs 1 inch apart inside. The flattened ends of the tubes are riveted and brazed to the outside upper corners of the U, and a bolt to carry the pulleys passes through the lower part, high enough to give clearance for 2-inch pulleys. This frame needs no diagonal wires.

Running Gear. Passing now to the running gear, the builder will encounter the most difficult part of the entire machine, and it is impossible to avoid the use of a few special castings. The general plan of the running gear is shown in the drawing of the complete machine, Figs. 23 and 24, while some of the details are illustrated in Fig. 27, and the remainder are given in the detail sheet, Fig. 28. It will be seen that each of the two wheels is carried in a double fork, the lower fork acting simply as a radius rod, while the upper fork is attached to a slide which is free to move up and down on a 2-inch steel tube. This slide is held down by two tension springs, consisting of either rubber tubes or steel coil springs, which absorb the shocks of landing. The whole construction is such that the wheels are free to pivot sideways around the tubes, so that when landing in a quartering wind the wheels automatically adjust themselves to the direction of the machine.

Framework. The main framework of the running gear consists of two horizontal beams, two vertical struts, and two vertical tubes. The beams are of ash, $4\frac{3}{4}$ inches wide in the middle half, tapering to $3\frac{3}{4}$ inches at the ends, and 5 feet $2\frac{3}{4}$ inches long overall. The upper beam is $\frac{13}{16}$ inch thick and the lower 1 inch. The edges of the beams are rounded off except at the points where they are drilled for bolt holes for the attachment of other parts. The two upper beams of the fuselage rest on these beams and are secured to them by two $\frac{3}{16}$-inch bolts each.

The vertical struts are also of ash, $1\frac{3}{16}$ inch by 3 inches and 4 feet 2 inches long overall. They have tenons at each end which fit into corresponding square holes in the horizontal beams. The two lower fuselage beams are fastened to these struts by two $\frac{3}{16}$-inch through bolts and steel angle plates formed from $\frac{1}{16}$-inch sheet steel. The channel section member across the front sides of these struts is for the attachment of the motor, and will be taken up later. The general arrangement at this point depends largely on what motor is to be used, and the struts should not be rounded or drilled for bolt holes until this has been decided.

From the lower ends of these struts *CC*, Fig. 27, diagonal struts *DD* run back to the fuselage. These are of ash, $1\frac{3}{16}$ by $2\frac{1}{2}$ inches and 2 feet 6 inches long. The rear ends of the struts *DD* are fastened to the fuselage beams by the projecting ends of the **U**-bolts of the horizontal fuselage struts, and also by angle plates of sheet steel. At the lower front ends the struts *DD* are fastened to the struts *CC* and the beam *E* by steel angle plates, and the beam is reinforced by other plates on its under side.

Trussing. In the genuine Bleriot, the framework is trussed by a single length of steel tape, $1\frac{1}{8}$ by $\frac{1}{16}$ inch and about 11 feet long, fastened to **U**-bolts in the beam *A*, Fig. 27. This tape runs down one side, under the beam *E*, and up the other side, passing through the beam in two places, where suitable slots must be cut. The tape is not made in this country, but must be imported at considerable

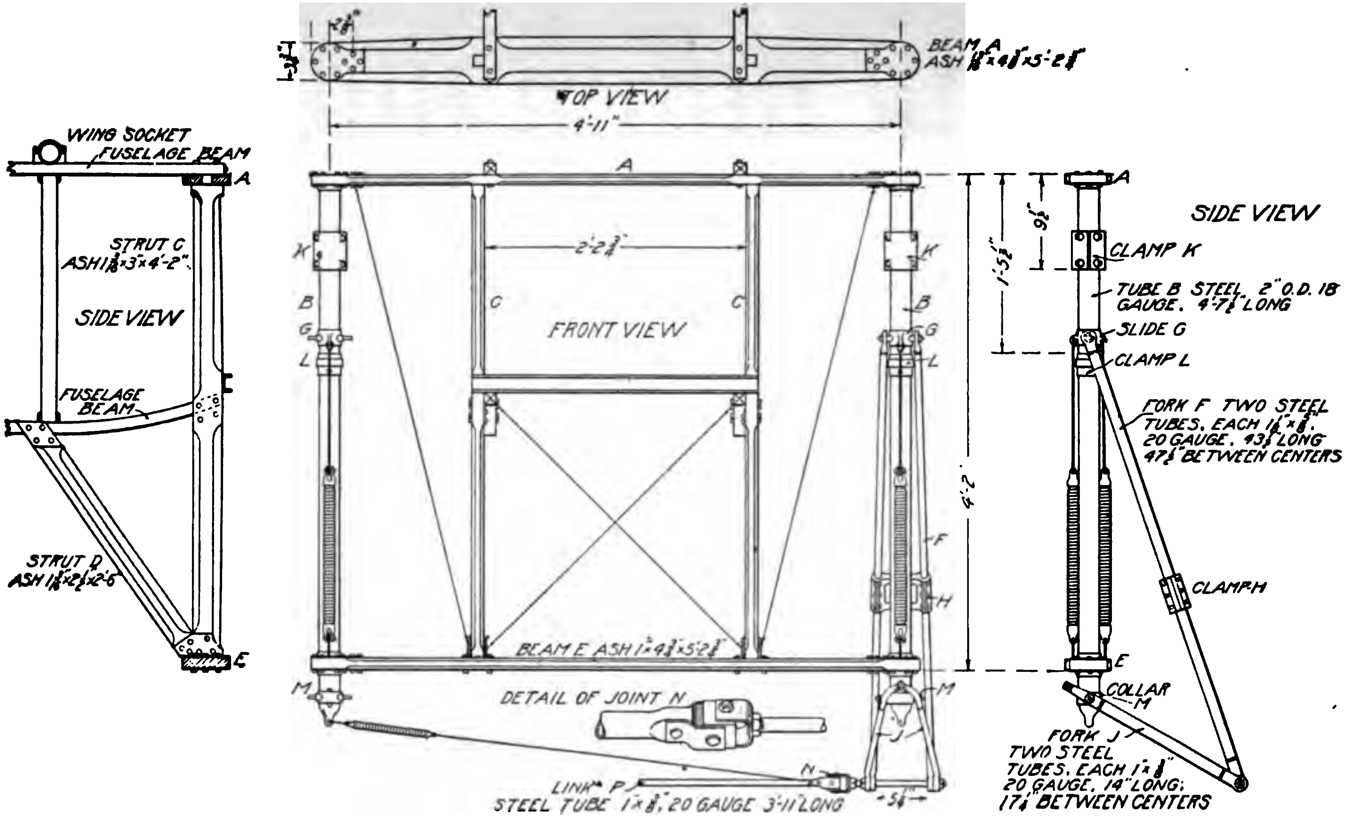

Fig. 27. Details of Bleriot Running Gear

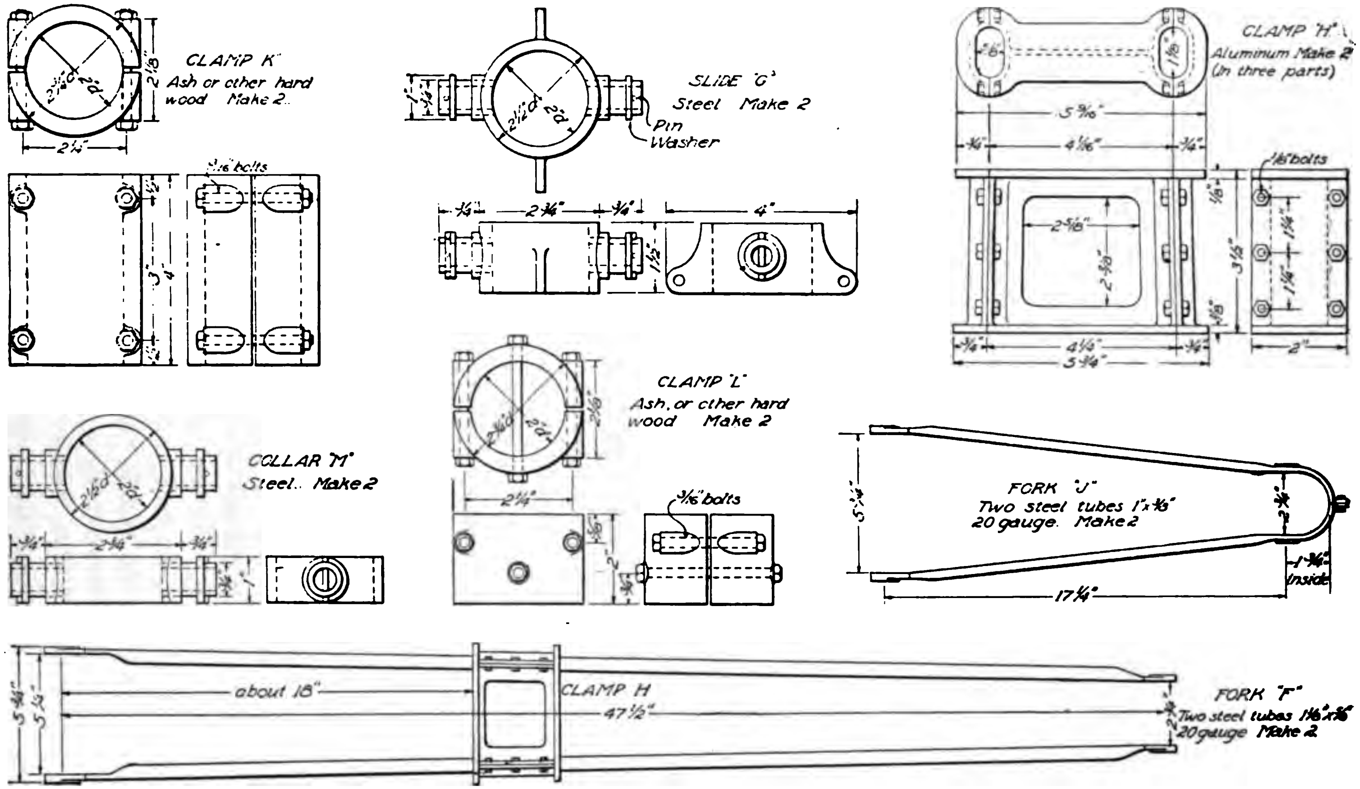

Fig. 28. Details of Various Fittings for Bleriot Monoplane

expense. Ordinary sheet steel will not do. If the tape can not be obtained, a good substitute is $\frac{1}{8}$-inch cable, which then would be made in two pieces and fastened to eye bolts at each end.

The two steel tubes are 2 inches in diameter, 18-gauge, and about 4 feet 10 inches long. At their lower ends they are flattened, but cut away so that a 2-inch ring will pass over them. To these flattened ends are attached springs and wires which run from each tube across to the hub of the opposite wheel. The purpose of these is simply to keep the wheels normally in position behind the tubes. The tubes, it will be noticed, pass through the lower beam, but are sunk only $\frac{1}{8}$ inch into the upper beam. They are held in place by sheet-steel sockets on the lower side of the upper beam and the upper side of the lower beam. The other sides of the beams are provided with flat plates of sheet steel. The genuine Bleriot has these sockets stamped out of sheet steel, but as the amateur builder will not have the facilities for doing this, an alternative construction is given here.

In this method, the plates are cut out to pattern, the material being sheet steel $\frac{1}{16}$ inch thick, and a $\frac{1}{2}$-inch hole drilled through the center, a 2-inch circle then being drawn around this. Then, with a cold chisel a half dozen radial cuts are made between the hole and the circle. Finally this part of the plate is heated with a blow-torch and a 2-inch piece of pipe driven through, bending up the triangular corners. These bent up corners are then brazed to the tubes, and a strip of light sheet steel is brazed on to cover up the sharp edges. Of course, the brazing should not be done until the slides *GG*, Figs. 27 and 28, have been put on. When these are once in place, they have to stay on and a breakage of one of them, means the replacement of the tube as well. This is a fault of the Bleriot design that can not well be avoided. It should be noticed that the socket at the upper end, as well as its corresponding plate on the other side of the beam, has extensions which reinforce the beam where the eye bolts or U-bolts for the attachment of the steel tape pass through.

Forks. Next in order are the forks which carry the wheels. The short forks *JJ*, Figs. 27 and 28, which act simply as radius rods, are made of 1- by $\frac{3}{8}$-inch oval tubing, a stock size which was specified for the overhead truss frame. It will be noticed that these are in two parts, fastened together with a bolt at the front end. The regular Bleriot construction calls for forged steel eyes to go in the ends of tubes, but these will be hard to obtain. The construction shown in the drawings is much simpler. The ends of the tubes are heated and flattened until the walls are about $\frac{1}{16}$ inch apart inside. Then a strip of $\frac{1}{16}$-inch sheet steel is cut the right width to fit in the flattened end of the tube, and brazed in place. The bolt holes then pass through the combined thickness of the tube and the steel strip, giving a better bearing surface, which may be further increased by brazing on a washer.

The long forks *FF*, which transmit the landing shocks to the springs, are naturally made of heavier material. The proper size tubing for them is $1\frac{1}{8}$ by $\frac{5}{8}$ inches, this being the nearest equivalent to the 14 by 28 mm French tubing. However, this is not a stock size in this country and can only be procured by order, or it can be made by rolling out $\frac{15}{16}$-inch round tubing. If the oval tubing can not be secured, the round can be employed instead, other parts being modified to correspond. The ends are reinforced in the same way as described for the small forks.

These forks are strengthened by aluminum clamps *II*, Figs. 27 and 28, which keep the tubes from spreading apart. Here, of course, is another call for special castings, but a handy workman may be able to improvise a satisfactory substitute from sheet steel. On each tube there are four fittings: At the bottom, the collar *M* to which the fork *J* is attached, and above, the slide *G* and the clamps *K* and *L*, which limit its movement. The collar and slide should be forged, but as this may be impossible, the drawings have been proportioned for castings. The work is simple and may be done by the amateur with little experience. The projecting studs are pieces of $\frac{3}{4}$-inch, 14-gauge steel tubing screwed in tight and pinned, though if these parts be forged, the studs should be integral.

The clamps which limit the movement of the slides are to be whittled out of ash or some other hard wood. The upper clamp is held in place by four bolts, which are screwed up tight; but when the machine makes a hard landing the clamp will yield a little and slip up the tube, thus deadening the shock. After such a landing, the clamps should be inspected and again moved down a bit, if necessary. The lower clamps, which, of course, only keep the wheels from hanging down too far, have bolts passing clear through the tubes.

To the projecting lugs on the slides *GG* are attached the rubber tube springs, the lower ends connecting with eye bolts through the beam *E*. These rubber tubes, of which four will be needed, are being made by several companies in this country and are sold by supply houses. They should be about 14 inches long, unstretched, and 1¼ inches in diameter, with steel tips at the ends for attachment.

Hub Attachments. The hubs of the two wheels are connected with the link *P*, with universal joints *N N* at each end. In case the machine lands while drifting sidewise, the wheel which touches the ground first will swing around to head in the direction in which the machine is actually moving, and the link will cause the other wheel to assume a parallel position; thus the machine can run diagonally on the ground without any tendency to upset.

This link is made of the same 1- by ⅜-inch oval tubing used elsewhere in the machine. In the original Bleriot, the joints are carefully made up with steel forgings. But joints which will serve the purpose can be improvised from a 1-inch cube of hard wood and three steel straps, as shown in the sketch, Fig. 27. From each of these joints a wire runs diagonally to the bottom of the tube on the other side, with a spring which holds the wheel in its normal position. This spring should be either a rubber tube, like those described above, but smaller, or a steel coil spring. In the latter case, it should be of twenty ¾-inch coils of No. 25 piano wire.

Wheels. The wheels are regularly 28 by 2 inches, corresponding to the 700 by 50 mm French size, with 36 spokes of 12-gauge wire. The hub should be 5¼ inches wide, with a ⅝-inch bolt. Of course, these sizes need not be followed exactly, but any variations will involve corresponding changes in the dimensions of the forks. The long fork goes on the hub inside of the short fork, so that the inside measurement of the end of the big fork should correspond to the width of the hub, and the inside measurement of the small fork should equal the outside measurement of the large fork.

Rear Skid. Several methods are employed for supporting the rear end of the fuselage when the machine is on the ground. The first Bleriot carried a small wheel in a fork provided with rubber springs, the same as the front wheels. The later models, however, have a double U-shaped skid, as shown in Figs. 23 and 24. This skid is made of two 8-foot strips of ash or hickory ½ by ¾ inches, steamed and bent to the U-shape as shown in the drawing of the complete machine.

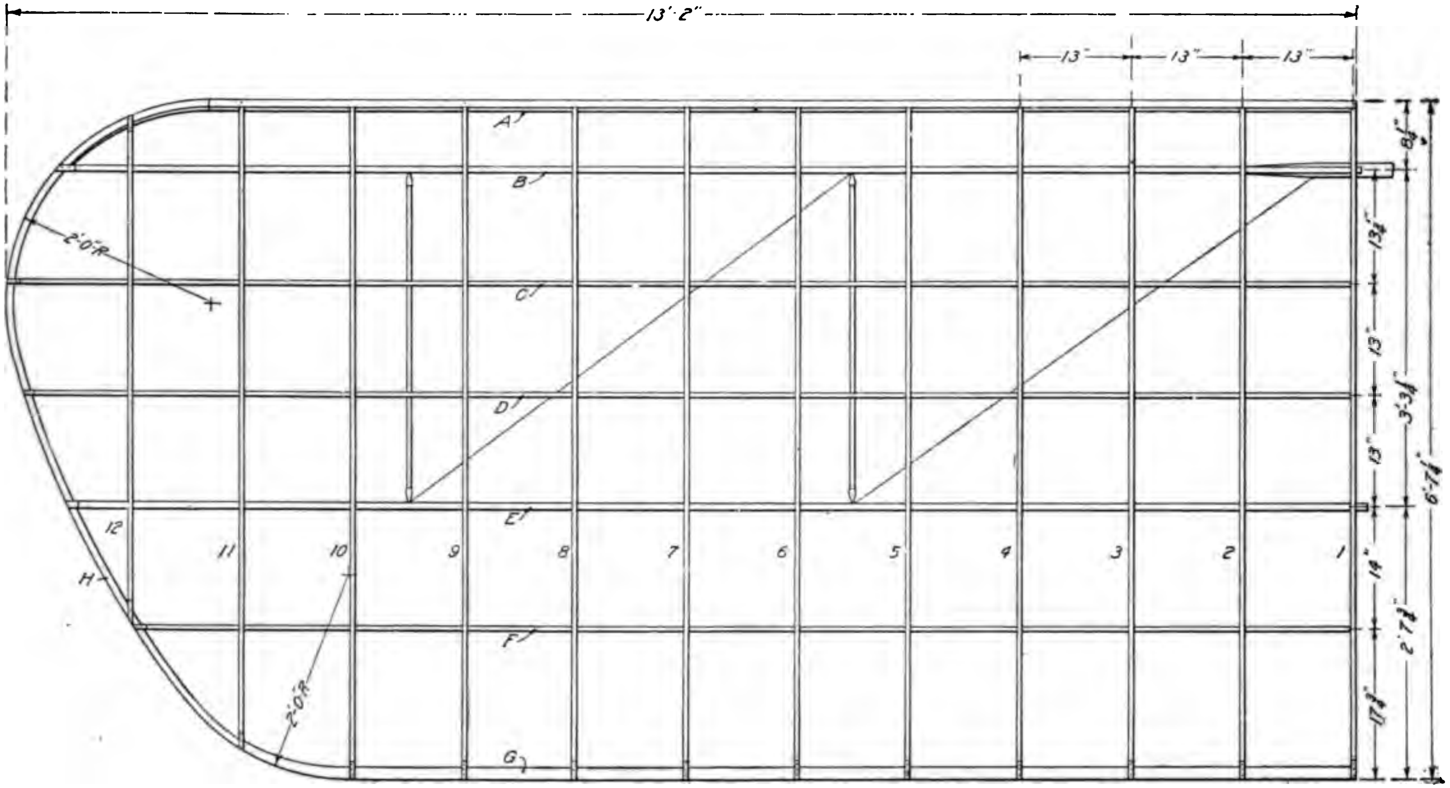

Fig. 29. Details of Framework of Bleriot Main Supporting Planes

Wings. Having completed the fuselage and running gear, the wings are next in order. These are constructed in a manner which may seem unnecessarily complicated, but which gives great strength for comparatively little weight. Each wing contains two stout ash beams which carry their share of the weight of the machine, and 12 ribs which give the proper curvature to the surfaces and at the same time reinforce the beams. These ribs in turn are tied together and reinforced by light strips running parallel to the main beams.

In the drawing of the complete wing, Fig. 29, the beams are designated by the letters *B* and *E*. *A* is a sheet aluminum member intended to hold the cloth covering in shape on the front edge. *C*, *D*, and *F* are pairs of strips (one strip on top, the other underneath) which tie the ribs together. *G* is a strip along the rear edge, and *H* is a bent strip which gives the rounded shape to the end of the wing. The ribs are designated by the numbers 1 to 12 inclusive.

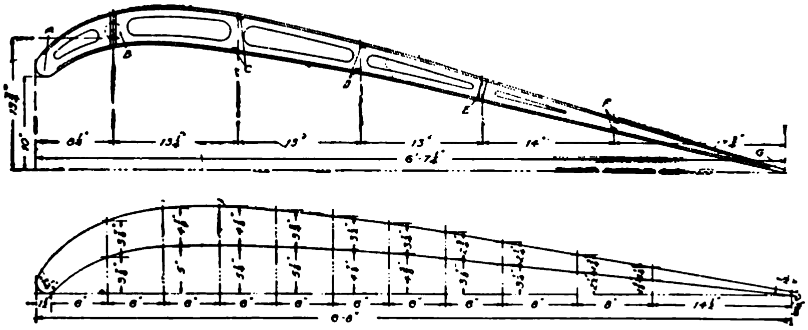

Fig. 30. Complete Rib of Bleriot Wing and Pattern from Which Web Is Cut

Ribs. The first and most difficult operation is to make the ribs. These are built up of a spruce board $\frac{3}{16}$ inch thick, cut to shape on a jig saw, with $\frac{3}{16}$- by $\frac{3}{8}$-inch spruce strip stacked and glued to the upper and lower edges. Each rib thus has an I-beam section, such as is used in structural steel work and automobile front axles. Each of the boards, or webs as they are usually called, is divided into three parts by the main beams which pass through it. Builders sometimes make the mistake of cutting out each web in three pieces, but this makes it very difficult to put the rib together accurately. Each web should be cut out of a single piece, as shown in the detail drawing, Fig. 30, and the holes for the beams should be cut in after the top and bottom strips have been glued on.

The detail drawing, Fig. 30, gives the dimensions of a typical rib. This should be drawn out full size on a strip of tough paper, and then a margin of $\frac{3}{16}$ inch should be taken off all round except at the front end where the sheet aluminum member *A* goes on. This allows for the thickness of the top and bottom strips. In preparing the pattern for the jig saw, the notches for strips *C*, *D*, and *F* should be disregarded; neither should it be expected that the jig-saw operator will cut out the oval holes along the center of the web, which are simply to lighten it. The notches for the front ends of the top and bottom strips should also be smoothed over in the pattern.

When the pattern is ready, a saw or planing mill provided with a saw suitable for the work, should cut out the 40 ribs (allowing a sufficient number for defective pieces and breakage) for about $2. The builder then cuts the notches and makes the oval openings with an auger and keyhole saw. Of course, these holes need not be absolutely accurate, but at least $\frac{3}{4}$ inch of wood should be left all around them.

Nine of the twelve ribs in each wing are exactly alike. No. 1, which forms the inner end of the wing, does not have any holes cut in the web, and instead of the slot for the main beam *B*, has a $1\frac{3}{4}$-inch round hole, as the stub end of the beam is rounded to fit the socket tube. (See Fig. 23.) Rib No. 11 is 5 feet $10\frac{1}{2}$ inches long, and No. 12 is 3 feet long. These can be whittled out by hand, and the shape for them will be obvious as soon as the main part of the wing is put together.

The next step is to glue on the top and bottom strips. The front ends should be put on first and held, during the drying, in a screw clamp, the ends setting close up into the notches provided for them. Thin $\frac{1}{2}$-inch brads should be driven in along the top and bottom at 1- to 2-inch intervals. The rear ends of the strips should be cut off to the proper length and whittled off a little on the inside, so that there will be room between them for the strip *G*, $\frac{1}{4}$ inch thick. Finally, cut the slots for the main beams, using a bit and brace and the keyhole saw, and the ribs will be ready to assemble.

Beams and Strips. The main beams are of ash, the front beam in each wing being $3\frac{1}{4}$ by $\frac{3}{4}$ inches and the rear beam $2\frac{1}{2}$ by $\frac{5}{8}$ inches. They are not exactly rectangular but must be planed down slightly on the top and bottom edges, so that they will fit into the irregularly-shaped slots left for them in the ribs. The front beams, as mentioned above, have round stubs which fit into the socket tube on the fuselage. These stubs may be made by bolting short pieces of ash board on each side of the end of the beam and rounding down the whole.

To give the wings their slight inclination, or dihedral angle, which will be apparent in the front view of the machine, the stubs must lie at an angle of 2½ degrees with the beam itself. This angle should be laid out very carefully, as a slight inaccuracy at this point will result in a much larger error at the tips. The rear beams project about 2 inches from the inner ribs. The ends should be reinforced with bands of sheet steel to prevent splitting, and each drilled with a ⅜-inch hole for the bolt which attaches to the fuselage strut. A strip of heavy sheet steel should be bent to make an angle washer to fill up the triangular space between the beam and the strut; the bolt hole should be drilled perpendicularly to the beam, and not to the strut. The outer ends of the beams, beyond rib No. 10, taper down to 1 inch deep at the ends.

The aluminum member *A*, Fig. 29, which holds the front edge of the wing in shape, is made of a 4-inch strip of fairly heavy sheet aluminum, rolled into shape round a piece of half-round wood, 2¼ inches in diameter. As sheet aluminum usually comes in 6-foot lengths, each of these members will have to be made in two sections, joined either by soldering (if the builder has mastered this difficult process) or by a number of small copper rivets.

No especial difficulties are presented by the strips, *C*, *D*, and *F*, which are of spruce $\frac{3}{16}$ by ⅝ inch, or by the rear edge strip *G*, of spruce ¼ by 1½ inches. Each piece *H* should be 1 by ½ inch half-round spruce, bent into shape, fitted into the aluminum piece at the front, and at the rear flattened down to ¼ inch and reinforced by a small strip glued to the back, finally running into the strip *G*. The exact curve of this piece does not matter, provided it is the same on both wings.

Assembling the Wings. Assembling the wings is an operation which demands considerable care. The main beams should first be laid across two horses, set level so that there will be no strain on the framework as it is put together. Then the 12 ribs should be slipped over the beams and evenly spaced 13 inches apart to centers, care being taken to see that each rib stands square with the beams, Fig. 31.

The ribs are not glued to the beams, as this would make repairs difficult, but are fastened with small nails.

Strips *C*, *D*, and *F*, Fig. 29, are next put in place, simply being strung through the rows of holes provided for them in the ribs, and fastened with brads. Then spacers of $\frac{3}{16}$-inch spruce, 2 or 3 inches long, are placed between each pair of strips halfway between each rib, and fastened with glue and brads. This can be seen in the broken-off view of the wing in the front view drawing, Fig. 23. The rear edge strip fits between the ends of the top and bottom strips of the ribs, as mentioned above, fastened with brads or with strips of sheet-aluminum tacked on.

Fig. 31. Assembling the Main Planes of a Bleriot Monoplane

Each wing is trussed by eight wires, half above and half below; half attached to the front and half to the rear beam. In the genuine Bleriot steel tape is used for the lower trussing of the main beams, similar to the tape employed in the running gear, but American builders prefer to use $\frac{1}{8}$-inch cable. The lower rear trussing should be $\frac{3}{32}$- or $\frac{7}{64}$-inch cable, and the upper trussing $\frac{3}{32}$-inch.

The beams are provided with sheet-steel fixtures for the attachment of the cables, as shown in the broken-off wing view, Fig. 23. These are cut from fairly-heavy metal, and go in pairs, one on each side of the and beam, fasten with three $\frac{3}{16}$-inch bolts. They have lugs top and bottom. They are placed between the fifth and sixth and ninth and tenth ribs on each side.

To resist the backward pressure of the air, the wings are trussed with struts of 1-inch spruce and $\frac{1}{16}$-inch cable, as shown in Fig. 23. The struts are placed between the cable attachments, being provided with ferrules of flattened steel tubing arranged to allow the rear beam freedom to swing up and down. The diagonal cables are provided with turnbuckles and run through the open spaces in the ribs.

Control System. The steering gear and tail construction of the Bleriot are as distinctive as the swiveling wheels and the U-bolts, and the word "cloche" applied to the bell-like attachment for the control wires, has been adopted into the international vocabulary of aeroplaning. The driver has between his knees a small steering wheel mounted on a short vertical post. This wheel does not turn, but instead the post has a universal joint at the bottom which allows it to be swung backward and forward or to either side. The post is really a lever, and the wheel a handle. Encircling the lower part of the post is a hemispherical bell—the cloche—with its bottom edge on the same level as the universal joint.

Four wires are attached to the edge of the cloche. Those at the front and back are connected with the elevator, and those at the sides with the wing-warping lever. The connections are so arranged that pulling the wheel back starts the machine upward, while pushing it forward causes it to descend, and pulling to either side lowers that side and raises the other. The machine can be kept on a level keel by the use of the wheel and cloche alone; the aviator uses them just as if they were rigidly attached to the machine, and by them he could move the machine bodily into the desired position.

In practice, however, it has been found that lateral stability can be maintained more easily by the use of the vertical rudder than by warping. This is because the machine naturally tips inward on a turn, and, consequently, a tip can be corrected by a partial turn in the other direction. If, for example, the machine tips to the right, the aviator steers slightly to the left, and the machine comes back to a level keel without any noticeable change in direction. Under ordinary circumstances this plan is used altogether, and the warping is used only on turns and in bad weather.

It will be noticed that the Bleriot control system is almost identical with that of the Henri Farman biplane, the only difference being that in the Farman the cloche and wheel are replaced by a long lever. The movements, however, remain the same, and as there are probably more Bleriot and Farman machines in use than all other makes together, this control may be regarded almost as a standard. It is not as universal as the steering wheel, gear shift, and brake levers of the automobile, but still it is a step in the right direction.

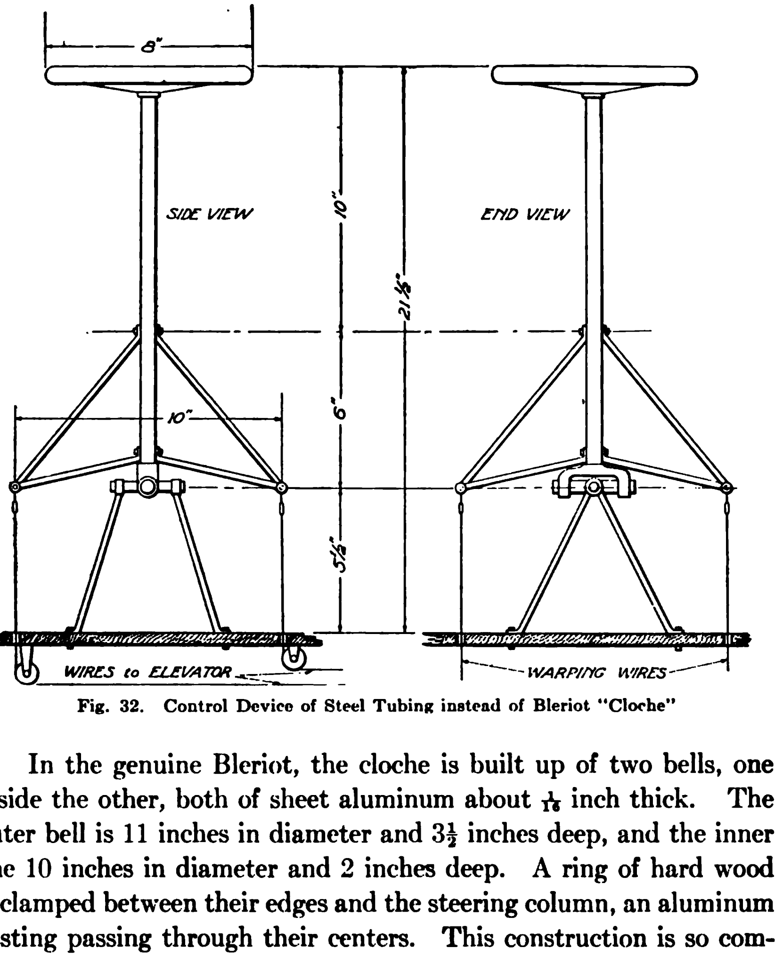

Fig. 32. Control Device of Steel Tubing instead of Bleriot "Cloche"

In the genuine Bleriot, the cloche is built up of two bells, one inside the other, both of sheet aluminum about 1/16 inch thick. The outer bell is 11 inches in diameter and 3½ inches deep, and the inner one 10 inches in diameter and 2 inches deep. A ring of hard wood is clamped between their edges and the steering column, an aluminum casting passing through their centers. This construction is so complicated and requires so many special castings and parts that it is almost impossible for the amateur.

Steering Gear. While not so neat, the optional construction shown in the accompanying drawing, Fig. 32, is equally effective. In this plan, the cloche is replaced by four V-shaped pieces of ½-inch, 20-gauge steel tubing, attached to a steering post of 1-inch, 20-gauge tubing. At the lower end, the post has a fork, made of pieces of smaller tubing bent and brazed into place, and this fork forms part of the universal joint on which the post is mounted. The cross of the universal joint, which is somewhat similar to those employed on automobiles, can best be made of two pieces of heavy tubing, ½ inch by 12 gauge, each cut half away at the middle. The two pieces are then fastened together by a small bolt and brazed for greater security. The ends which are to go into the fork of the steering post must then be tapped for ⅜-inch machine screws. The two other ends of the cross are carried on V's of ½-inch, 20-gauge tubing, spread far enough apart at the bottom to make a firm base, and bolted to the floor of the cockpit.

The steering wheel itself is comparatively unimportant. On the genuine Bleriot it is a solid piece of wood 8 inches in diameter, with two holes cut in it for hand grips. On the post just under the wheel are usually placed the spark and throttle levers. It is rather difficult, however, to arrange the connections for these levers in such a way that they will not be affected by the movements of the post, and for this reason many amateur builders place the levers at one side on one of the fuselage beams.

From the sides of the cloche, or from the tubing triangles which may be substituted for it, two heavy wires run straight down to the ends of the warping lever. This lever, together with two pulleys, is mounted at the lower point of the warping frame already described. The lever is 12 inches long, 11 inches between the holes at its ends, and 2 inches wide in the middle; it should be cut from a piece of sheet steel about $\frac{1}{16}$ inch thick. The pulleys should be 2½ inches in diameter, one of them bolted to the lever, the other one running free. The wires from the outer ends of the rear wing beams are joined by a piece of flexible control cable, which is given a single turn over the free pulley. The inner wires, however, each have a piece of flexible cable attached to their ends, and these pieces of cable, after being given a turn round the other pulley, are made fast to the opposite ends of the warping lever. These cables should be run over the pulleys, not under, so that when the cloche is pulled to the right, the left wing will be warped downward.

It is a common mistake to assume that both pulleys are fastened to the warping lever; but when this is done the outer wire slackens off and does not move in accord with the inner wire, on account of the different angles at which they work.

Foot Levers. The foot lever for steering is cut from a piece of wood 22 inches long, hollowed out at the ends to form convenient rests for the feet. The wires connecting the lever to the rudder may either be attached to this lever direct, or, if a neater construction is desired, they may be attached to another lever under the floor of the cockpit. In the latter case, a short piece of 1-inch steel tubing serves as a vertical shaft to connect the two levers, which are fastened to the shaft by means of aluminum sockets such as may be obtained from any supply house. The lower lever is 12 inches long and 2 inches wide, cut from $\frac{1}{16}$-inch steel similar to the warping lever.

Amateur builders often cross the rudder wires so that pressing the lever to the right will cause the machine to steer to the left. This may seem more natural at first glance, but it is not the Bleriot way. In the latter, the wires are not crossed, the idea being to facilitate the use of the vertical rudder for maintaining lateral equilibrium. With this arrangement, pressing the lever with the foot on the high side of the machine tends to bring it back to an even keel.

Tail and Elevator. The tail and elevator planes are built up with ribs and tie strips in much the same manner as the wings. However, it will hardly pay to have these ribs cut out on a jig saw unless the builder can have this work done very cheaply. It serves the purpose just as well to clamp together a number of strips of $\frac{3}{16}$-inch spruce and plane them down by hand. The ribs when finished should be $24\frac{1}{4}$ inches long. The greatest depth of the curve is $1\frac{1}{4}$ inches, at a point one-third of the way back from the front edge, and the greatest depth of the ribs themselves $2\frac{1}{4}$ inches, at the same point. Sixteen ribs are required.

A steel tube 1 inch by 20 gauge, *C*, Fig. 33, runs through both tail and elevators, and is the means of moving the latter. Each rib at the point where the tube passes through, is provided with an aluminum socket. Those on the tail ribs act merely as bearings for the tube, but those on the elevator ribs are bolted fast, so that

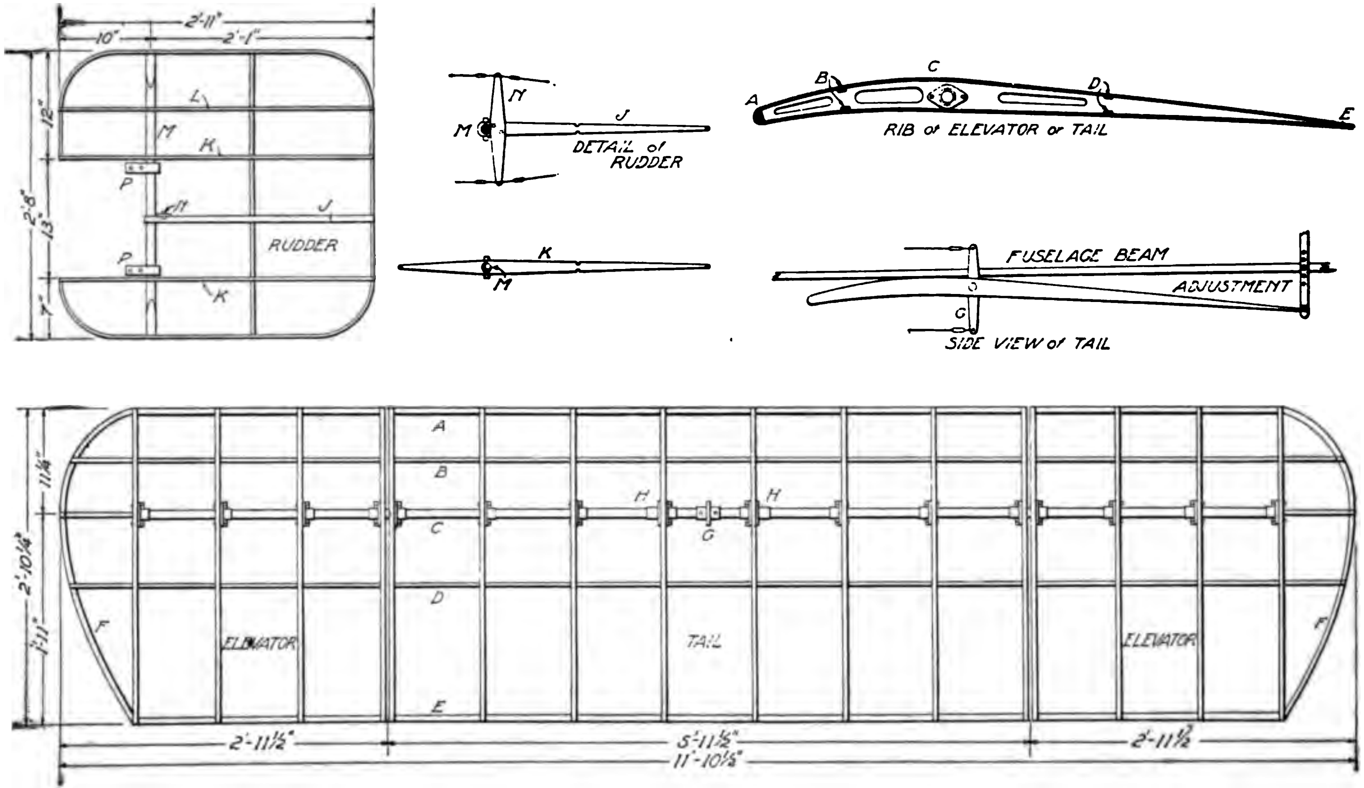

Fig. 33. Construction Details of Bleriot Tail, Elevators, and Rudder

the elevators must turn with the tube. At its center the tube carries a lever *G*, of $\frac{1}{16}$-inch steel 12 by 2 inches, fastened on by two aluminum sockets, one on each side. From the top of the lever a wire runs to the front side of the cloche, and from the bottom a second wire runs to the rear side of the cloche.

The tube is carried in two bearings *HH*, attached to the lower beams of the fuselage. These are simply blocks of hard wood, fastened by steel strips and bolts. The angle of incidence of the tail is adjustable, the tail itself being held in place by two vertical strips of steel rising from the rear edge and bolted to the fuselage, as shown in the drawing, Fig. 33. To prevent the tail from folding up under the air pressure to which it is subjected, it is reinforced by two $\frac{3}{4}$-inch, 20-gauge steel tubes running down from the upper sides of the fuselage, as shown in the drawing of the complete machine, Fig. 23.

The tail and elevators have two pairs of tie strips, *B* and *D*, Fig. 33, made of $\frac{3}{16}$- by $\frac{5}{8}$-inch spruce. · The front edge *A* is half round, 1- by $\frac{1}{2}$-inch spruce, and the rear edge *E* is a spruce strip $\frac{1}{4}$- by $1\frac{1}{2}$-inches. The end pieces are curved.

Rudder. The rudder is built up on a piece of 1-inch round spruce *M*, corresponding in a way to the steel tube used for the elevators. On this are mounted two long ribs *KK*, and a short rib *J*, made of spruce $\frac{3}{8}$ inch thick and $1\frac{3}{8}$ inches wide at the point where *M* passes through them. They are fastened to *M* with $\frac{1}{8}$-inch through bolts. The rudder lever *N*, of $\frac{1}{16}$-inch steel, 12 by 2 inches, is laid flat on *J* and bolted in place; it is then trussed by wires running from each end to the rear ends of *KK*. From the lever other wires also run forward to the foot lever which controls the rudder.

The wires to the elevator and rudder should be of the flexible cable specially made for this purpose, and should be supported by fairleaders attached to the fuselage struts. Fairleaders of different designs may be procured from supply houses, or may be improvised. Ordinary screw eyes are often used, or pieces of copper tubing, bound to the struts with friction tape.

Covering the Planes. Covering the main planes, tail, elevators, and rudder may well be left until the machine is otherwise ready for its trial trip, as the cloth will not then be soiled by the dust and grime of the shop. The cloth may be any of the standard brands which are on the market, preferably in a rather light weight made specially for double-surfaced machines of this type; or light-weight sail cloth may be used, costing only 25 or 30 cents a yard. About 80 yards will be required, assuming a width of 36 inches.

Except on the rudder, the cloth is applied on the bias, the idea being that with this arrangement the threads act like diagonal truss wires, thus strengthening and bracing the framework. When the cloth is to be put on in this way it must first be sewed together in sheets large enough to cover the entire plane. Each wing will require a sheet about 14 feet square, and two sheets each 6 feet square will be required for the elevators and tail. The strips of cloth run diagonally across the sheets, the longest strips in the wing sheets being 20 feet long.

Fig. 34. Method of Mounting Fabric on Main Supporting Frame

Application of the cloth to the wings, Fig. 34, is best begun by fastening one edge of a sheet to the rear edge of the wing, stretching the cloth as tight as can be done conveniently with one hand. The cloth is then spread forward over the upper surface of the wing and is made fast along the inner end rib. Small copper tacks are used, spaced 2 inches apart on the upper side and 1 inch on the lower side. After the cloth has been tacked to the upper sides of all the ribs, the wing is turned over and the cloth stretched over the lower side. Finally the raw edges are trimmed off and covered with light tape glued down, tape also being glued over all the rows of tacks along the ribs, making a neat finish and at the same time preventing the cloth from tearing off over the tack heads.

Installation of Motor. As stated previously, the ideal motor for a Bleriot-type machine is short along the crank shaft, as the available space in the fuselage is limited, and air-cooled for the same reason. Genuine Bleriots are always fitted with one of the special types of radial or rotary aeronautic motors, which are always air-cooled. Next in popularity to these is the two-cylinder, horizontal-opposed motor, either air- or water-cooled. However, successful machines have been built with standard automobile-type, four-cylinder, water-cooled motors, and with four-cylinder, two-cycle, aeronautic motors.

When the motor is water-cooled, there will inevitably be some difficulty in finding room for a radiator of sufficient size. One scheme is to use twin radiators, one on each side of the fuselage, inside of the main frame of the running gear. Another plan is to place the radiator underneath the fuselage, using a supplementary water tank above the cylinders to facilitate circulation. These two seem to be about the only practicable arrangements, as behind the motor the radiator would not get enough air, and above it would obstruct the view of the operator.

It is impossible to generalize to much effect about the method of supporting the motor in the fuselage, as this must differ with the motor. Automobile-type motors will be carried on two heavy ash beams, braced by lengths of steel tubing of about 1 inch diameter and 16 gauge. When the seven-cylinder rotary Gnome motor is used, the crank shaft alone is supported; it is carried at the center of two X-shaped frames of pressed steel, one in front of and the other behind the motor. The three-cylinder Anzani motors are carried on four lengths of channel steel bent to fit around the upper and lower portions of the crank case, which is of the motorcycle type.

Considerable care should be taken to prevent the exhaust from blowing back into the operator's face as this sometimes carries with it drops of burning oil, besides disagreeable smoke and fumes. The usual plan is to arrange a sloping dashboard of sheet aluminum so as to deflect the gases down under the fuselage.

The three sections of the fuselage back of the engine section are usually covered on the sides and bottom with cloth like that used on the wings. Sometimes sheet aluminum is used to cover the section between the wing beams. However, those who are just learning to operate machines and are a little doubtful about their landings often leave off the covering in order to be able to see the ground immediately beneath their front wheels.

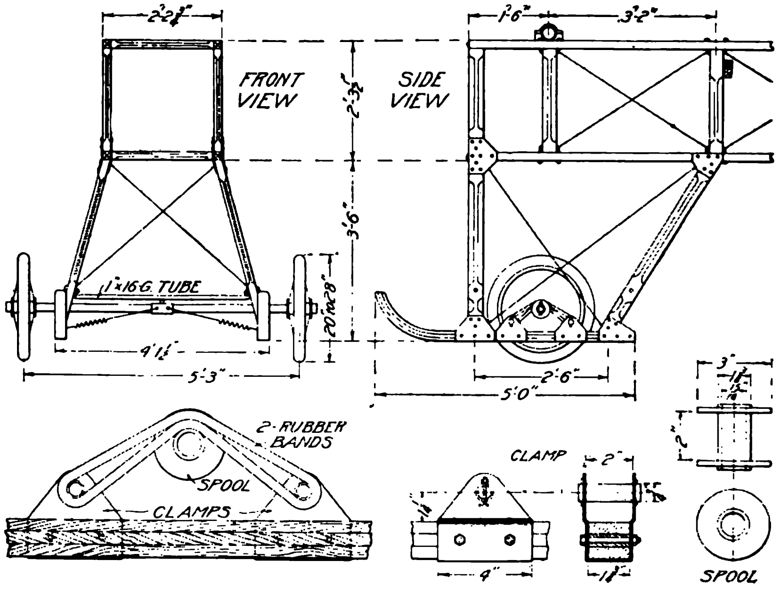

Fig. 35. Running Gear of Morane Type of Bleriot Monoplane

New Features. *Morane Landing Gear.* Although the regular Bleriot landing gear already described, has many advantages and has been in use with only detail changes for several years, some aviators prefer the landing gear of the new Morane monoplane, which in other respects closely resembles the Bleriot. This gear, Fig. 35, is an adaptation of that long in use on the Henri Farman and Sommer biplanes, combining skids and wheels with rubber-band springs. In case a wheel or spring breaks, whether due to a defect or to a rough landing, the skids often save an upset. Besides, the tension of the springs is usually such that on a rough landing the wheels jump up and allow the skids to take the shock; this also prevents the excessive rebound of the Bleriot springs under similar conditions.

Another advantage which may have some weight with the amateur builder, is that the Morane running gear is much cheaper and easier to construct. Instead of the two heavy tubes, the four forks of oval tubing, and the many slides, collars, and blocks—most of them special forgings or castings—the Morane gear simply requires two short laminated skids, four ash struts, and some sheet steel.

The laminated skids are built up of three boards each of ⅝- by 2-inch ash, 3½ feet long. These must be glued under heavy pressure in forms giving the proper curve at the front end. When they are taken from the press, three or four ½-inch holes should be bored at equal distances along the center line and wood pins driven in; these help in retaining the curve. The finished size of the skids should be 1¾ by 1¾ inches.

Four ash struts 1¼ by 2½ inches support the fuselage. They are rounded off to an oval shape except at the ends, where they are attached to the skids and the fuselage beams with clamps of 1/16-inch sheet steel. The ends of the struts must be beveled off carefully to make a good fit; they spread out 15 degrees from the vertical, and the rear pair have a backward slant of 30 degrees from vertical.

Additional fuselage struts must be provided at the front end of the fuselage to take the place of the struts and beams of the Bleriot running gear. The two vertical struts at the extreme front end may be of the same 1¼- by 2½-inch ash used in the running gear, planed down to 1 3/16 inches thick to match the thickness of the fuselage beams. The horizontal struts should be 1 3/16 by 1¾ inches.

The wheels run on the ends of an axle tube, and usually have plain bearings. The standard size bore of the hub is 15/16 inch, and the axle tube should be 15/16 inch diameter by 11 gauge. The tube also has loosely mounted on it two spools to carry the rubber band springs. These are made of 2¼-inch lengths of 1⅜-inch tubing, with walls of sufficient thickness to make an easy sliding fit on the axle tube. To the ends of each length of tube are brazed 2½-inch washers of 3/16-inch steel, completing the spool.

The ends of the rubber bands are carried on rollers of ¾-inch, 16-gauge tubing, fastened to the skids by fittings bent up from $\frac{3}{16}$-inch sheet steel. Each fitting is bolted to the skid with two ⅜-inch bolts.

Some arrangement must now be made to keep the axle centered under the machine, as the rubber bands will not take any sidewise strain. A clamp of heavy sheet steel should be made to fit over the axle at its center, and from this heavy wires or cables run to the bottom ends of the forward struts. These wires may be provided with stiff coil springs, if it is desired to allow a little sidewise movement.

New Bleriot Inverse Curve Tail. Some of the latest Bleriot machines have a new tail which seems to add considerable to their speed. It consists of a fixed tail, Fig. 36, nearly as large as the old-style tail and elevators combined, with two elevator flaps hinged to its rear edge. The peculiarity of these elevators, from which the tail gets its name, is that the curve is concave above and convex below—at first glance seeming to have been attached upside down.

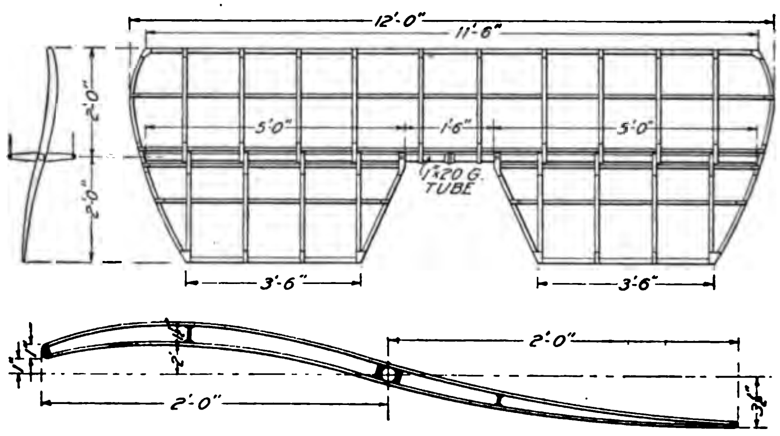

Fig. 36. Details of Bleriot Inverse Curve Tail

In this construction, the 1-inch, 20-gauge tube, which formerly passed through the center of the tail, now runs along the rear edge, being held on by strips of ½- by $\frac{1}{16}$-inch steel bent into **U**-shape and fastened with screws or bolts to the ribs. Similar strips attach the elevators to the tube, but these strips are bolted to the tube.

The construction is otherwise like that previously described. It is said that fitting this tail to a Bleriot in place of the old-style tail adds 5 miles an hour to the speed, without any other changes being made.

Another slight change which distinguishes the newer Bleriots is in the overhead frame, which now consists of a single inverted **V** instead of two **V**'s connected by a horizontal tube. The single **V** is set slightly back of the main wing beam, and is higher and, of course, of heavier tubing than in the previous construction. Its top should stand 2 feet 6 inches above the fuselage, and the tubing should be 1 inch 18 gauge. It also requires four truss wires, two running to the front end of the fuselage and two to the struts to which the rear wing beams are attached. All of the wires on the upper side of the wings converge to one point at the top of this **V**, the wires from the wing beams, of course, passing over pulleys.

These variations from the form already described may be of interest to those who wish to have their machines up-to-date in every detail, but they are by no means essential. Hundreds of the old-style Bleriots are flying every day and giving perfect satisfaction.

ART OF FLYING

Knowledge of the science of aeronautics and ability to fly are two totally different things. Long-continued study of the problem from its scientific side enabled the Wright Brothers to learn how to build a machine that would fly, but it did not teach them how to fly with it. That came as the result of persistent attempts at flying itself. A study of the theoretic laws of balancing does not form a good foundation for learning how to ride a bicycle—practice with the actual machine is the only road to success. The best evidence of this is to be found in the fact that several of the most successful aviators today have but a slight knowledge of the science of aeronautics. They are not particularly well versed in what makes flight possible, but they know how to fly because they have learned it in actual practice.

Reference to the early work of the Wright Brothers shows that during a period of several years they spent a large part of their time in actual experiments in the air, and it was not until these had proved entirely satisfactory that they attempted to build a power-driven machine.

Methods Used in Aviation Schools. Aviation schools are springing up all over this country and there are a number of well-established institutions of this kind abroad. In the course of instruction, the student must first learn the use of the various controls on a dummy machine. In the case of an English school, this dummy, Fig. 37, is a motorless aeroplane mounted on a universally-jointed support so as to swing about a pivot as desired. This is employed for the purpose of familiarizing the beginner with the means of maintaining equilibrium in the air.

Fig. 37. Monoplane Dummy Used for Practice in Aviation Schools

Fig. 38. Aerocycle with Treadle Power for Practice Work

A French school, on the other hand, employs a wingless machine, which is otherwise complete, as it consists of a regulation chassis with motor and propeller, all steering and elevating controls. On this, the student may practice what has come to be familiarly known as "grass-cutting," to his heart's content, without any danger of the machine taking to the air unexpectedly, as has frequently been the case where first attempts have been made on a full-fledged machine. Usually, most of such attempts result disastrously, often destroying in a moment the result of months of work in building the machine.

Fig. 39. Voisin Biplane with Double Control for Teaching Beginners

A French aerocycle, Fig. 38, a comparatively inexpensive machine, is also useful for practice in balancing and in short, low flights. The French apparatus in question may accordingly be considered an advance, not only over the English machine, even of the type shown in Fig. 39, which has a double control, and is especially designed for the teaching of beginners, but very much over the practice of attempting to actually fly for the first time in a strange machine, as it provides the necessary practice in the handling of the motor and the lateral steering. The machine can make high speed over the ground, but is perfectly safe for the beginner, as it is incapable of rising. Having gone through the stages represented by either of these contrivances, the best course for the learner to follow is to try gliding, taking short glides to attain the ability to quickly meet varying conditions of the atmosphere.

The fact that these glides are of extremely short duration at first need not be discouraging when it is recalled that, after several years of work, the Wright Brothers considered that great progress had been made when, in 1902, they were able to make glides of 26 seconds. During six days of the practice season of that year, they made 375 gliding flights of various distances, most of them comparatively short, but each one of value in familiarizing the glider with the conditions to be met. It is not material whether gliding or manipulation of the control levers is taken up first, as both should be mastered as far as possible before attempting to fly a regular machine.

Use of the Elevating Plane. So many things are necessary to the control of an aeroplane that thinking becomes entirely too slow a process—the aviator must be endowed with something approaching the instinct of the bird; he must be so familiar with his machine and its peculiarities that a large part of the work of controlling it is the result of subconscious movement. The control levers of many machines are so arranged that this subconscious movement on the part of the aviator directly operates the balancing mechanism. There is no time to think. When a machine rises from the ground, facing the wind as it should, its path of flight should be a gradual upward inclination, this being something difficult to accomplish at first, owing to the sensitiveness of the elevating rudder, the tendency almost invariably being to give the latter too great an angle of incidence. At this stage, the maximum velocity of flight has not yet been attained and care must be taken to keep the angle of ascent small. Otherwise, the power of the engine, which may not have reached its maximum, would not be sufficient to cause the machine to ascend an inclined path at the starting speed. If the speed of flight be reduced by the increased resistance at this point, the whole machine will slide back in the air, and if a sudden gust of wind happens to coincide with the attempt to rise at too great an angle, there is danger of it being blown over backward.

Where the machine is just leaving the ground and the elevator has been set at an excessive angle, the rear end of the skids or the tail may slap the ground hard and break off, or they will impose so much resistance upon its movement by scraping over the turf that the machine can not attain its soaring speed. It must be borne in mind, of course, that remarks such as the present can be only of the most general nature, every type of machine having its own peculiarities—in some instances, the extreme opposite of those characterizing similar machines. For example, in the Voisin 1910 type, the very large and powerful light tail tends to lift before the main planes, and if this be not counteracted, the whole machine may turn up on its end. In order to offset this tendency, the elevator must be raised so as to keep sufficient pressure beneath it; the moment of this pressure about the center of gravity must be at least equal to the pressure under the tail planes about the center of gravity of the machine, or the tail will rise unduly in the air. At least that is the theory of it—naturally, only practice with that particular machine would suffice to enable an aviator to familiarize himself with that particular peculiarity. Again, some machines are "tail heavy." But there is great difficulty in even approximating the degree of relative motion, for which reason it has been suggested, under "Accidents and Their Lessons," that a gradometer, or small spirit level, in plain sight of the aviator, should form part of the equipment of every machine. The Wrights long ago adopted the expedient of attaching a strip of ribbon to the elevator to provide an indication of motion relative to the wind.

Aeroplane in Flight. The sensation of motion after the machine leaves the ground is almost imperceptible, and it is likewise extremely difficult to tell at just what moment the aeroplane ceases running on the solid ground and takes to the air. There is a feeling of exhilaration but very little of motion. Whereas 40 miles an hour over the ground, particularly in an automobile, brings with it a lively appreciation of the speed of travel, the same speed in an aeroplane is a very gentle motion when high above the ground. If there be no objects close at hand, with which to compare the speed, the sense of motion is almost entirely lost.

Center of Gravity. The static balance of a machine should be carefully tried before commencing to fly, and particularly that of a biplane of the Wright type, in which the aviator sits beside the engine.

When provision is made for carrying a passenger, his seat is placed in the center line of the machine, so that his presence or absence does not materially affect the question of lateral balance. As men are not all of the same weight, in cases in which the aviator only partly balances the engine about the center line, his weight being insufficient for the purpose, extra weights should be placed on the wing tip at the lightest end until the true balance is secured, otherwise a permanent warping, or *gauchissement* as the French term it, is required at this side in order to keep the machine on an even keel. In other words, the machine will carry what sailors term a port helm where the left side of the machine is lighter than the right, and *vice versa,* and it will be necessary to keep the rudder over to that side slightly during the entire flight to counteract this tendency.

In aeroplanes fitted with tails, the center of gravity is usually in the vicinity of the trailing edge of the main planes and, of course, should be on the center line of the machine. The center of gravity of the aviator on a monoplane should approximately coincide with that of the machine. If this be not the case, the stabilizers or the elevator must be permanently set to produce longitudinal balance. Much downward set, or the increase of the angle of incidence of the tail, will create undue resistance to flight and should be avoided when possible by bringing the weight farther forward. The center of pressure should coincide with the center of gravity, and balance will result.

Before even ground work is attempted, the position of the center of gravity should be determined in the manner shown in Fig. 40, the approximate location for four types of machines being shown. At what point the machine must be suspended, so that it can tip only frontward and backward and be evenly balanced, is a question that must be answered in order to ascertain the probability of the machine's pitching forward whenever mud, grass, or rough ground is encountered in alighting. If the center of gravity should lie in front of the axles of the ground wheels in a machine of the Farman type, trouble is sure to follow. Always consider the relation of the center of gravity to the wheels, in order that you may gain some idea of the distribution of the weight on the running gear when the machine is tipped forward 10 degrees. If the wheels are not forward far enough there will be trouble in running on the ground. The elevators must correct whatever variance there may be from the correct center of gravity and position of the wheels, and the manipulation of the elevators for that purpose requires skill. If the tail be very heavy, the elevator may not be able to counteract that defect.

The position of the center of gravity of a machine in regard to lateral stability in flight is a matter of far greater importance than untried aviators realize. Having it too low is quite as bad as too high, as in either case there is a tendency to upset. Although the dihedral angle is considered wasteful of power, it seems to do more to secure inherent stability than any other device. Devices for maintaining stability automatically are to be frowned upon in the present state of the art. The sensitive perception and quick response which come with intimate knowledge of a machine's peculiarities, are at present worth more than gyroscopes and pendulums. To acquire this intimate knowledge, the aviator must familiarize himself thoroughly with the machine; he must become so accustomed to controls that he and the machine are literally one. A practiced bicycle rider does not have to think about balance, neither does the practiced aviator, yet he must always be prepared to meet motor stoppages, unusual air disturbances, and breakages. A leap from the ground directly into the air, without preliminary practice, means certain accident, to put it mildly.

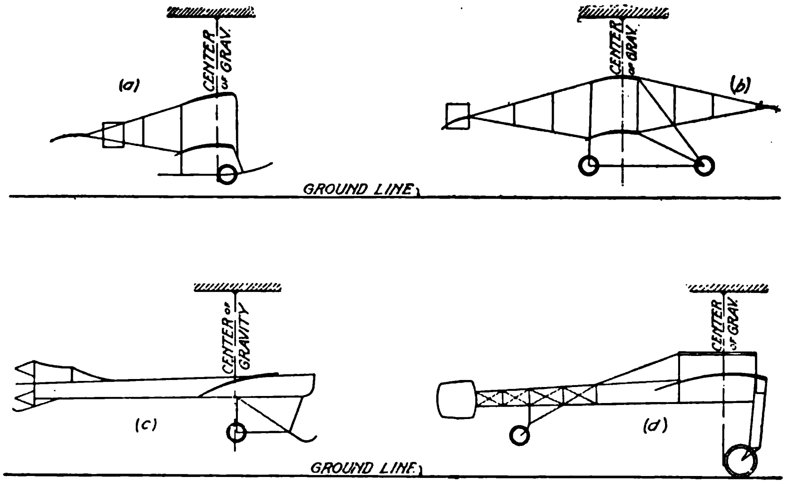

Fig. 40. Method of Determining Center of Gravity of Different Types of Machines

Center of Pressure. But although the center of gravity remains approximately constant, the center of pressure is continually varying and is never constant for many seconds. The center of pressure on an aerocurve constructed to Phillips' design, Fig. 41, is about one-third of the chord from the leading edge of the plane under normal conditions, *i. e.*, when the angle of incidence is about 8 degrees between the direction of motion of the plane and that of the air. At the moment this angle is increased the center of pressure moves toward the rear, and *vice versa.* The center of gravity must be moved to coincide with this new position, or the center of pressure must be artificially restored by the use of supplementary planes or elevators, moving in a contrary direction. A forward movement of the center of pressure tends to lower the tail of the machine, when the intensity of the pressure is unchanged, and to counterbalance this the rear elevator must have its angle of incidence increased in order to increase the lift at the rear of the machine, or it will slide down backward. The alternative to be adopted in case of temporary lack of engine power is to decrease the angle of the elevator and allow the aeroplane to sweep downward, thus gaining momentum. The increase of speed will then be sufficient probably to enable the machine to continue in a horizontal flight, when the center of pressure is again restored to its normal position.

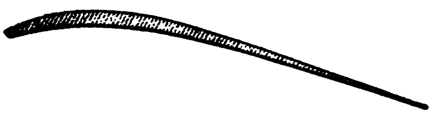

Fig. 41. Aerocurve of Phillip's Design

Ground Practice. First of all, the aviator should familiarize himself with his seat for it is from that place that he must judge wind effects, vibration, motor trouble, and the thousand and one little creaks and hums that will ultimately mean so much to him. Not until he has thoroughly accustomed himself to his seat, should he try to run along the ground. This done, hours should be spent running up and down and around the field to learn the use of the rudder, particularly on rough ground. The runs should be straight so that when the time comes to leap into the air, the aviator may be sure that he is on an even keel, and flying straightaway. In order to prevent the possibility of leaving the ground unexpectedly in practice, trials should be made only in calm weather and with the motor well throttled down so that the machine will be reduced to a speed of not more than 15 miles per hour. After a time this may be increased to 20, but the latter is the maximum for ground practice, as the machine will rise at speeds slightly exceeding this. In these practice runs on the ground, the student should learn to gauge the rush of air against his face, as when aloft his best gauge will be the wind pressure on his cheeks, as that will tell him whether he is moving with sufficient speed to keep up or not. It will also tell him ultimately whether he is moving along the ground fast enough to leap up.

In this stage of experimenting on the ground, the elevator is kept neutral as far as possible. With increasing skill its use may be ventured, but only sparingly, for it takes very little to lift the machine from the ground with a speed in excess of 20 miles per hour. It will soon be discovered that the elevator can be used as a brake to prevent pitching forward. The tail elevators on the Farman or Bleriot running gear are very effective owing to the blast of the propeller, even when the main planes are not moving forward at lifting speed. With the Curtiss type of running gear and a front elevator only, it is often possible at 18 to 20 miles per hour to raise the front wheel off the ground for a second or two—facts which indicate that at 25 to 28 miles per hour, the elevator is far more effective.

First Flight. The first actual flight should be confined to a short trip parallel to the ground and not more than one or two feet above it. At first, the student should see how close he can fly to the ground without actually touching it, which he can do by gradually increasing his forward speed. This must be done in an absolute calm as an appreciable amount of wind will bring in too many other factors for the student to master at so early a stage. This practice should be continued in calm air until short, straight flights can be made a foot or two from the ground with the motor wide open. If it be found that the machine barely flies straightaway with the full power of the motor, the latter is either badly out of adjustment, or a more powerful engine is required. In an under-powered machine turning would be suicidal. Moreover, the resistance encountered in the air is greater than on the ground and may be such that the speed is not sufficient for sustentation. Fig. 42, (a) and (b), show why it is possible to run along the ground faster than it is possible to travel in the air, under certain conditions, and why the ground can be left at low speed. If it were possible to drive a machine with such enormous projected areas as BB, shown in Fig. 42 (b), a man could fly slowly for an indefinite period. But the projected area is greater than the air displaced by the propeller, and it is impossible to fly except with a moderate angle of incidence, giving projected areas AA, Fig. 42 (a).

The student, as he increases in skill, may venture to a height of 10 feet, which should be maintained as accurately as before, and after making a run of 100 yards, the machine should be pointed down, but ever so slightly. The wind pressure on the face immediately becomes greater. Within a foot or two of the ground the motor should be cut off or throttled. This should be tried ten or fifteen times, and the height increased to 30 or 40 feet, in order that the student may familiarize himself with the sensation of coasting. At the end of each glide the machine will seem to become more responsive, as indeed it does, for gliding down greatly increases the efficiency of the elevator and other controls, because of the increased speed. Gliding down steep angles is often the aviator's salvation in a tight place, particularly when the motor fails, a side gust threatens, or an air pocket is encountered.

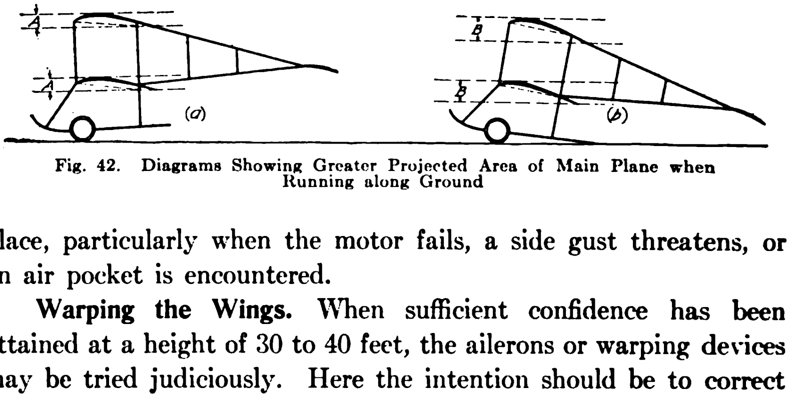

Fig. 42. Diagrams Showing Greater Projected Area of Main Plane when Running along Ground

Warping the Wings. When sufficient confidence has been attained at a height of 30 to 40 feet, the ailerons or warping devices may be tried judiciously. Here the intention should be to correct any tendency to side tipping, and not purposely to incline the machine as far as possible without actually causing a wreck. The use of the lateral control may cause the machine to swerve a little, but that may be ignored. Before landing, a straight course should be taken so that the machine will always come down on an even keel. With increasing practice, the student may fly higher, but always with the understanding that there is a limit to the angle of incidence. An automobile is retarded when it strikes a short, steep hill; so is an aeroplane. No aeroplane has yet been built that can take a steep angle and climb right up that grade continuously. Altitude is reached by a series of small steps and at comparatively low angles, as unless the course is straightened out at regular intervals, a machine will lose its speed and tend to plunge tail first, just as is the case when an attempt is made to rise from the ground at too sharp an angle.

In warping the wings an increase of lift imparted to one wing of the machine is produced by increasing the angle of incidence of the whole or part of the wing, or by an increase of pressure under that wing, and will tend to cause that side of the machine to rise and the other side to lower, the result being that the machine will be liable to slide through the air diagonally. In the majority of aeroplanes there are no fins or keels to counteract this movement, and lateral stability must be restored by artificially increasing the lift of the depressed wing. This can be done by warping, or lowering the trailing edge of the depressed wing and increasing its lift, and simultaneously raising the trailing edge of the other wing, thus decreasing the angle of incidence of the latter and reducing its lifting effect. This applies to flight on a straight course, whatever the cause may be that tends to upset lateral stability. It will be seen, therefore, that the center of gravity remains constant and the center of pressure must be manipulated to restore stability. This manipulation is much more rapid and positive than the alteration of the center of gravity by the movement of the aviator's body resorted to in the early gliding flights of pioneer experimenters.

Making a Turn. The first turn should be made over a large field and the diameter of the turn should be at least half a mile. The height should be not less than 50 feet. After that level has been maintained, the rudder should be moved very gingerly. The machine will lean in almost immediately, because the outer end travels at a higher speed than the inner and therefore has a greater lift. Warping or working the ailerons should be resorted to as a means of counteracting this tendency, and the rudder swung to the opposite direction, if necessary. It is obvious that if the rudder will cause the machine to bank when swung in one direction, it will right the machine again when swung in the opposite direction. It is even possible to turn the machine on an even keel by anticipating the banking, simply by correctly using the rudder, which was necessary in the old Voisin machine flown by Farman in 1908, because it had no mechanical lateral control. The student should learn the correct angle of banking, *i. e.*, the angle at which the machine will neither skid nor slide down and which is most economical of power because it requires less use of the lateral controls. The necessity of "feeling the air" is greater in turning than in any other phase of flying. By "feeling the air" is meant the ability to meet any contingency intuitively and not until this is acquired can the student become an expert aviator. When it has been acquired, safe flying is assured and is dependent only upon the integrity of the planes, motor, and controls. By using the rudder discreetly and by banking simply far enough to partially offset the centrifugal force of turning, the use of the lateral control will not be necessary in still air. Even too short a turn can be corrected by a quick use of the rudder.

The peculiarities existing between different types of monoplanes become even more marked than between the biplane and the monoplane. For example, in piloting a Bleriot monoplane, Fig. 43, it is necessary to take into account the effect of the engine torque. As the engine rotates in a right-hand direction, from the point of view of the pilot, the left wing tends to rise in the air, owing to the depression of the right side of the machine. The machine also tends to turn to the right, and this must be counteracted by putting the rudder over to the left. An aeroplane answers its controls with comparative slowness, with the exception, perhaps, of the Wright machine, which is noted for its sensitive and quick response to every movement of the levers. All control movements must, therefore, be very gentle, as the behavior of an aeroplane is more like that of a boat than that of an automobile. The action of the elevator has already been described, and it is, perhaps, the most difficult of all the controls to manipulate, in that it requires the exercise of a new sense. The direction rudder is naturally a more familiar type of control, and in action is similar to the rudder of a boat.

The torque of the motor renders it advisable for a novice to turn his machine to the right, if a right-hand propeller be used, and *vice versa*. If two propellers, turning in opposite directions, are employed, as in the Wright biplane, there is no inequality from the torque of the motor. Since torque is not noticeable in straight flying, straightening out again will always serve the student when he finds himself in trouble on a turn. When the use of the rudders and ailerons has reduced the speed, a downward glide will increase

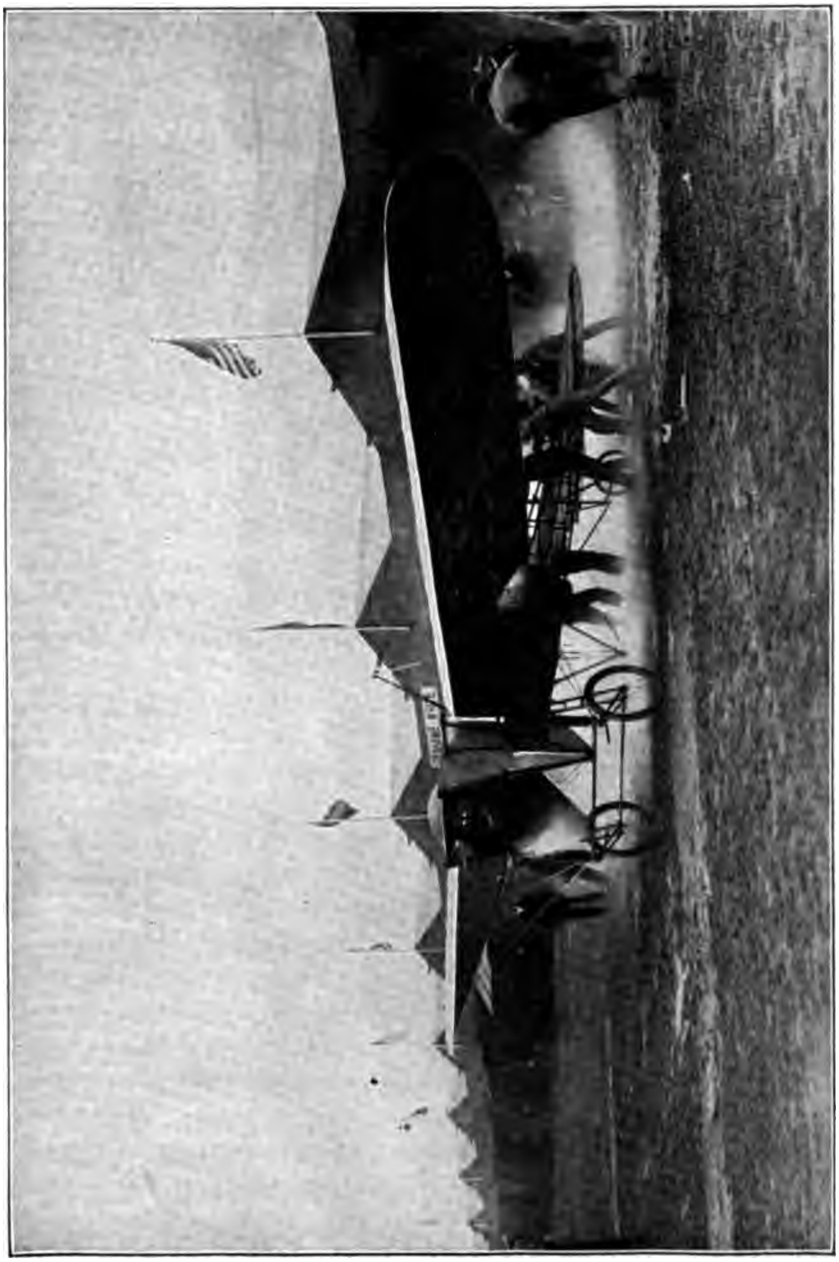

Fig. 43. Making a Start with Bleriot Monoplane

it again, and if the motor should stop on a turn, such a downward glide is immediately imperative. When the machine is thus gliding, a change in the fore-and-aft balance becomes at once apparent, because the blast of the propeller no longer acts on the tail, and the elevator must then be used with greater amplitude to obtain the same effect.

Only by constant practice in calm air can the student familiarize himself with exactly the amount of warping and rudder control to employ to properly offset the lowering of the inner wing in rounding a turn. If this be not corrected, the whole machine tends to bank excessively and will be apt to slide downward in a diagonal direction, Fig. 44. This is a perilous position for the aviator and must be guarded against by the manipulation of the warping control so as to increase the lift of the inner wing of a biplane, at the same time, employing the rudder to counteract this tendency. The use of the rudder is of even greater importance on the monoplane, as, in this case, warping the inner wing tends to direct the whole machine downward instead of raising the inner wing itself. Several bad accidents have resulted from monoplanes refusing to respond to the warping of the inner wing when making a turn. In such machines, the rudder must be practically always employed in connection with the warping of the wings in order to keep the machine on an even keel, although the controls may not actually be interconnected, this being one of the grounds on which foreign manufacturers are trying to make use of the Wright principle, without infringing the Wright patents, as while they employ warping in connection with the simultaneous use of the rudder, the controls are not attached to the same lever as in the Wright machine.

Lateral resistance must also be taken into consideration in turning, otherwise the machine, if kept on an even keel, will tend to skid through the air and turn about its center of gravity as a pivot. In the case of an automobile, the resistance to lateral displacement is great, though on a greasy surface it may be small, as when the machine skids sideways, a suitable banking of the road being necessary to prevent this on turns. Many hold that the banking of the aeroplane on turns is only the direct effect of the turning itself, but the fallacy of this will be apparent upon a consideration of the law of centrifugal force. It is obvious that to make a turn, some force

Fig. 44. An Aeroplane "Banking" as it Rounds a Pylon

must be imparted to the machine to counteract the effect of the centrifugal force upon the machine as a whole. And as the sidewise projection of the machine is small, a compensating force must be introduced. This can be done only by previously banking up the machine on the outer wing, so that the pressure of the air under the main plane can counteract the tendency to lateral displacement. The force then acting under the planes is in a diagonal direction, and the angle at which it is inclined vertically depends upon the banking of the planes, it being normal to their greater dimension. This force can be resolved into two forces, one perpendicular and one horizontal, the magnitude of each being dependent upon the degree of banking. When the speed of the machine is higher, the amount of banking must be greater in order to increase the value of the horizontal component in proportion to the increase of the value of the centrifugal force at the higher speed, in spite of the fact that the forces acting under the planes are also greater due to the higher speed.

As the curve commences, the rudder being put over, the difference of the pressures. on the two wings, owing to their different flying speeds comes into account, as already explained, and care must be taken that the banking does not increase abnormally. When the turn is completed, the rudder is straightened and the machine is again brought to an even keel with the aid of the wing-warping control, or the ailerons. The effect of a reverse warping to prevent excessive banking, lowering the inside wing tip incidentally, puts a slight drag on that wing and assists in the action of turning, as does also the provision of small vertical planes between the elevator planes of the original Wright machine. Since the adoption of the headless type, these surfaces are placed between the forward ends of the skids and the braces leading down to them.

In making a turn, say, to the left, the outside or right-hand wing is first raised by lowering the wing tip on that side and the rudder is then put over to the left. When the correct amount of banking is acquired, the wing tip is restored to its normal position, and probably the left wing tip may have to be lowered slightly to increase the lift on that side owing to its reduced speed. When the turn is completed, the rudder is straightened out and the left wing tip lowered to restore the machine to an even keel. Both Glenn

Curtiss in this country and R. E. Pelterie in France have shown that it is possible to maneuver without using the rudder at all, the ailerons or wing tips alone being relied upon for this purpose.

Before flights in other than calm air are attempted, much practice is required. The machine must be inspected over and over again, and the wind variations studied with a watchful eye. Not until this familiarity with machine and atmosphere be acquired should flying in a wind be attempted. To the man on the ground, wind is simply air moving horizontally, but to the man in the air it is quite different. Not only must he consider horizontal movement, but vertical draughts and vortices as well. A rising current of air lifts a machine, a downward current depresses it, and he must learn to take advantage of the former as the birds do. Horizontal currents affect forward speed over the ground; swirls and vortices create inequalities in wind pressure on the planes and disturb lateral balance. Familiarity with all these atmospheric conditions can be acquired only after long practice. Against every tree, house, hill, fence, and hedge beats an invisible surf of air; upward currents on one side and downward on the other. The upward draught is not usually dangerous, for it simply lifts the machine; but the down draught will cause it to drop. A swift downward glide under the full power of the motor must then be made, to increase the forward speed and consequently the lift. This explains why it is dangerous to fly near the ground in a wind; likewise why the beginner should never attempt flying at first in anything but a dead calm.

Turning in a Wind. When turning in a wind, two velocities must be borne in mind, that of the machine relative to the air and that relative to the earth. The former is limited at its lower value to that of the flying speed of the machine, and the latter must be considered on account of the momentum of the machine as a whole. Change of momentum is a matter of horse-power and weight and is the governing factor in flying in a wind on a circular course. Suppose the flying speed of a machine is a minimum of 30 miles an hour relative to the air, and a wind of 20 miles an hour is blowing. The actual speed of the machine relative to the earth in flying against the wind will be 10 miles an hour. If it be desired to turn down the wind, the speed of the machine relative to the earth must be increased from 10 miles to 50 miles an hour during the turn and a corresponding change of momentum must be overcome. There are two ways of accomplishing this, either by speeding up the motor to give the maximum power, or by rising just previous to making the turn and then sweeping down as the turn is made, thus utilizing the acceleration due to gravity to assist the motor. The wind's velocity will assist the machine also and during the turn it will make considerable leeway, a small amount of which is deducted to counteract the centrifugal force of the machine.

Turning in a contrary direction, *i. e.*, up into the wind when running with it, requires considerable skill, as when flying 50 miles an hour, the tendency on rounding a corner into a 20-mile-an-hour wind would be for the machine to rise rapidly in the air. The centrifugal force at such a speed is also considerable, causing the machine to make much leeway with the wind during the turn. Turning under such circumstances should be commenced early, particularly if there are any obstructions in the vicinity, and considerable skill should be acquired before an attempt is made to fly in such a wind.

Starting and Landing. A machine should always be started and landed in the teeth of the wind, and no one but the most experienced aviators can afford to disregard this advice, certainly not the novice. The precaution is necessary because in landing the machine should always travel straight ahead without the possibility of lurching and consequently breaking a wing, as frequently happens. Contact with the ground is necessarily made at a time when the machine is traveling over it at a speed of 30 to 40 miles per hour and skidding sideways at 10 to 15 miles per hour, all circumstances which tend to wreck an aeroplane.

Planning a Flight. It is easy to lose one's way in the air. For that reason it is best to follow the Wright idea of starting out with a definite plan, and of landing in some predetermined spot, as aimless wandering about may prove disastrous to the inexperienced aviator. He may forget which way the wind was blowing, or how much fuel he had, or the character of the ground beneath him. Should the motor stop, he may make an all too hasty decision in landing. It is an easy matter to lose one's bearings in the air, not only because the vehicle is completely immersed in the medium in which it is traveling, but also because the earth assumes a new aspect from the seat of an aeroplane. Cecil Grace was one of those who lost his bearings and, as a consequence, his life. Ordinary winds blowing over a level country can be negotiated with comparative safety. Not so the puffy wind. To cope with that, constant vigilance is required, particularly in turning. In a circular flight in a steady wind, the only apparent effect is that the earth is swept over faster in one direction than in the other. Before a cross-country flight is attempted, the starting field should be circled over at a great height, as not until then may the long distance flight be started in safety. Cross-country flying is, of course, fascinating, and it is a sore temptation, at an altitude of a few hundred feet, to throw off all caution and fly off over that strange country below, which is, indeed, a new land as viewed from aloft. To quote a professional aviator: "Here the greatest self-restraint must be exercised. Not until the necessary practice has been acquired, not until the right kind of confidence has been gained, may one of these trips be attempted, and then only after it has been properly planned."

Training the Professional Aviator. Look back over the achievements in the air during the comparatively short time that man has actually been flying, and it will be noted that the beginners, burning up with the enthusiasm of the novice, have performed the most spectacular feats and flown with the greatest fearlessness. Curtiss was comparatively new at aviation when he won the Gordon-Bennett at Rheims in 1909. John B. Moisant, the sixth time he ever went up in an aeroplane, flew from Paris to London with a 187-pound passenger and 302 pounds of fuel, oil, and spare parts. Hamilton made his successful flight from New York to Philadelphia and return when he was hardly more than a novice, while Atwood's great flights from St. Louis to New York and Boston to Washington were made before his name had become known, and Beachey had been flying only a few months when he broke the world's altitude record at Chicago, while more recent achievements, notably Dixon's flight across the Rockies, have emphasized the work of the beginner. All of this substantiates the belief held at every aviation headquarters in the country—namely, that the older men already in aviation may improve the art by executive ability and scientific experiments, but most of them will degenerate as flyers. Beyond a certain point, frequency of flight does not necessarily create a feeling of confidence and safety; rather it brings a fuller appreciation of the dangers, and the men who best know how to fly are most content to stay upon the ground.

Professional aviators are drawn from every walk of life, but trick bicycle performers, acrobats, parachute jumpers, and racing automobile drivers make the most promising applicants. By a kind of sixth sense, both the Wrights and Curtiss weed out the promising ones after a brief examination. They select men who have an almost intuitive sense of balance. Most of these, provided they have nerve, have in them the stuff of which aviators are made, even though they may have had no experience in any line akin to aviation. Neither Curtiss nor the Wrights will accept women under any condition. The Moisant school does not share this discrimination and trained three women for pilot's licenses during 1911.

Curtiss and the Wrights are keen in their realization that recklessness is pulling a wing feather from aviation every time a man is killed, and they are doing their utmost to promote conservatism. Curtiss said in an interview:

> I do not encourage and never have encouraged fancy flying. I regard the spectacular gyrations of several aviators I know as foolhardy and unnecessary. I do not believe that fancy or trick flying demonstrates anything except an unlimited amount of a certain kind of nerve and perhaps the possibilities of what is valueless—aerial acrobatics. Some aviators develop the sense of balance very rapidly, while others acquire it only after long practice. It may be developed to a large extent by going up as a passenger with an experienced man. Therefore, in teaching a beginner, I make it a point to have him make as many trips as possible with someone else operating the machine. In this way the pupil gains confidence, becomes accustomed to the sensation of flying, and is soon ready for a flight on his own hook. This is the method used in training army and navy officers to fly. I have never seen novices more cautious and yet more eager to fly than these young officers. They have always learned every detail of their machines before going aloft, and largely because of this they have developed into great flyers. Perhaps it is due to the military bent of their minds; at any rate, they have made good almost without exception.

ACCIDENTS AND THEIR LESSONS

Press Reports. Whenever an industry, profession, or what not, is prominently before the public, every event connected with it is regarded as "good copy" by the daily press. Happenings of so insignificant a nature that in any commonplace calling would not be considered worthy of mention at all, are "played up." This is particularly the case with fatalities, and the eagerness to cater to the morbid streak in human nature has been responsible for the unusual amount of attention devoted to any or all accidents to flying machines, and more especially where they have a fatal ending. In fact, this has led to the chronicling of many deaths in the field of aviation that have not happened—some of them where there was not even an accident of any kind. For instance, in many of the casualty lists published abroad from time to time, such flyers as Hamilton, Brookins, and others have figured among those who have been killed, ever since the date of mishaps that they had months ago.

It will be recalled that five years ago, when the automobile began to assume a very prominent position, every fatality for which it was responsible was heralded broadcast where deaths caused by other vehicles would not be accorded more than local notice. To a large extent, this is still true and will probably continue to be the case until the automobile assumes a rôle in our daily existence as commonplace as the horse-drawn wagon and trolley car. There is undoubtedly ample justification for this and particularly for the editorial comment always accompanying it, where the number of lives sacrificed to what can be regarded only as criminal recklessness is concerned. Still, the fact that in a city like New York the truck and the trolley car are responsible for an annual death roll more than twice as large as that caused by the automobile, does not call for any particular mention. Horses and wagons, we have always had with us, and the trolley car long since became too commonplace an institution around which to build a sensation.

As the most novel and recent of man's accomplishments, the conquest of the air and everything pertaining to it is a subject on which the public is exceedingly keen for news and nothing appears to be of too trivial import to merit space. Where an aviator of any prominence is injured, or succumbs to an accident, the event is accorded an amount of attention little short of that given the death of some one prominent in official life. During the four years that aviation has been to the fore, about 104 men and one woman have been killed, not including the deaths of three or four spectators resulting from accidents to aeroplanes, during this period—*i. e.*, from the beginning of 1908 to the end of 1911. In view of the lack of corroboration in some cases, the figures are made thus indefinite.

Naturally most of these deaths have occurred in 1910 and 1911—in fact, 50 per cent took place from 1908 to the end of 1910, and the remainder during 1911, since these years were responsible for a far greater development, and particularly for a greater increase in the number engaged, than ever before. More was accomplished in these two years than in the entire period intervening between that day in December, 1903, when the Wright Brothers first succeeded in leaving the ground in a power-driven machine, and the beginning of 1910.

Fatal Accidents. Conceding that the maximum number mentioned, 105, were killed during the four years in question, throughout the world, it will doubtless come as a surprise to many to learn that this is probably not quite twice the number who have succumbed to football accidents during the same time in the United States alone. Authentic statistics place the number thus killed at 13 during 1908, 23 in 1909, 14 during 1910, and 17 in 1911, or a total of 67. But we have been playing football for a couple of centuries or more and this is regarded as a matter of course. The death of a football player occurring in some small, out-of-the-way place would not receive more than local attention, unless there were other reasons for giving it prominence, so that, in all probability, the statistics in question fall far short of the truth, rather than otherwise.

The object of mentioning this phase of the matter is to place the question of accidents in its true light. That the development of any new art is bound to be attended by numerous mishaps, many of them fatal, goes without saying and it is something that can not be ignored. Nothing could be worse than attempting to gloss over or belittle the loss of life for which aviation has been responsible and doubtless will continue to be. Progress invariably takes its toll and it is more often founded upon failure than unvarying success, for every accident is a failure, in a sense, and every accident carries with it its own lesson.

Where the cause is apparent, it gives an indication of the remedy which will bring about the prevention of its recurrence. In other words, it serves to point out weaknesses and shows what is necessary to overcome them. For that reason alone is the question of accidents taken up here, as a study of those that have occurred points the way to improvement. Table III gives a resumé of the more impor-

Fatal Aeroplane Accidents

Date	Aviator	Nationality	Locality	Machine		Probable Cause
				Type	Make	
Sept. 17–08	Lt. Selfridge	American	Ft. Myer, Va.	Biplane	Wright	B
Sept. 7–09	E. Lefebvre	French	near Paris	Biplane	French Wright	A or B
Sept. 22–09	Capt. Ferber	French	Boulogne	Biplane	Voisin	C
Dec. 6–09	A. Fernandez	Spanish	near Nice	Biplane	Fernandez	B
Jan. 4–10	L. Delagrange	French	Bordeaux	Monoplane	Bleriot	B
Apr. 2–10	H. Le Blon	French	San Sebastian	Monoplane	Bleriot	B
May 13–10	Hauvette-Michelin	French	Lyons	Monoplane	Antoinette	C
June 18–10	T. Robl	German	Stettin	Biplane	Aviatik	A
July 3–10	C. Wachter	French	Rheims	Monoplane	Antoinette	B
July 15–10	D. Kinet	Belgian	Ghent	Biplane	H. Farman	C
July 12–10	C. S. Rolls	English	Bournemouth	Biplane	French Wright	B
Aug. 3–10	N. N. Kinet	Belgian	Brussels	Biplane	H. Farman	A
Aug. 20–10	Lt. Vivaldi	Italian	Monte Mario	Biplane	M. Farman	A
Aug. 27–10	C. Van Maasdyk	Dutch	Arnhem	Biplane	Sommer	A
Sept. 25–10	E. Poillot	French	Chartres	Biplane	Savary	A
Sept. 27–10	G. Chavez	Peruvian	Domodossola	Monoplane	Bleriot	B
Sept. 29–10	E. Plochman	German	Mulhausen	Biplane	Aviatik	A
Oct. 1–10	H. Haas	German	Wellen	Biplane	German Wright	B
Oct. 7–10	Capt. Mazievitch	Russian	St. Petersburg	Biplane	H. Farman	B
Oct. 23–10	Capt. L. Madiot	French	Douai	Biplane	Breguet	A
Oct. 25–10	Lt. W. Mente	German	Magdeburg	Biplane	German Wright	B
Oct. 26–10	F. Blanchard	French	Paris	Monoplane	Bleriot	B
Oct. 27–10	Lt. Saglietti	Italian	Rome	Biplane	Asteria	A
Nov. 17–10	R. Johnstone	American	Denver	Biplane	Wright	B
Dec. 3–10	Cecil Grace	American	England	Biplane	English Wright	D
Dec. 3–10	Engr Camarota and a private	Italian	Rome	Biplane	H. Farman	A
Dec. 31–10	J. B. Moisant	American	New Orleans	Monoplane	Bleriot	B
Dec. 31–10	Arch. Hoxsey	American	Los Angeles	Biplane	Wright	B

A—represents loss of control or the result of some miscalculation on the part of the aviator through inexperience, lack of judgment, or similar cause.

B—covers causes that may be summed up as a failure of the machine in some essential. Either a vital part broke through weakness due to excessive air pressure, failed from vibration or similar cause, or loosened and came in contact with the propeller or other moving part.

C—colliding with obstruction either on the ground or in flight. This is practically a subdivision of A, so far as the actual cause of the accident is concerned, but as there were only two fatalities from this particular cause, they are given a separate classification.

D—lost at sea.

tant fatalities that have resulted from the use of a heavier-than-air machine during the *past four years:*

Fatalities greatly increased in number during 1911, but not out of proportion to the greatly augmented number of aviators. With comparatively few exceptions, however, the accidents were more or less similar in their nature to those already tabulated, so that it would be of no particular value to extend the comparison in this manner to cover them. Many of the fatalities during that year were not of the aviators themselves, but of the spectators, a fact which calls attention to a danger that has not been fully appreciated before. At the start of the Paris-Madrid race, the French minister of war and another official were killed by a monoplane plunging into the crowd, and on the same day, May 21, 1911, five people were killed at Odessa, Russia, in the same manner. An unusual type of mishap, not mentioned in the tabulation and in which three or four aviators lost their lives during 1911, was the burning of the aeroplane in midair, or the explosion of the gasoline, setting fire to the wings and either burning the aviator at his post or killing him by the fall. One such accident occurred in France in September, another in Spain two days later, and a third in Germany, in which two men were killed. Accidents of an even more unusual nature were the collision of two biplanes in midair at St. Petersburg, the collision of a motorcycle with a biplane as it swooped down on a race track, and the partial wrecking of Fowler's biplane by a bull upon landing near Fort Worth, Texas, but these, of course, had no bearing on the design of the machines.

Apart from those specially referred to, the great majority of accidents during 1911 may be ascribed to two or three of the causes detailed in connection with the comparative table. Of these, lack of experience and foolhardiness stand out prominently, the latter undoubtedly causing the double fatality at Chicago when two aeroplanes plunged into Lake Michigan, drowning one of the aviators, while a third machine collapsed in mid-air, hurling the aviator to his death on the field. Careful reading of the reports of a large number of these accidents usually brings to light the statement "in attempting to make a quick turn," or similar phrase, showing that the moving cause of the accident was due to subjecting the parts of the machine to excessive stresses, as outlined in the following pages.

Causes. *Lack of Experience.* It will be at once noticeable by Table III that out of a total of 28, no less than 16, or considerably more than half of the accidents, were due in one way or another to lack of experience. In other words, the aviators had not fully complied with the cardinal principle for success in flying upon which the Wright Brothers have always laid so much stress, *i. e.*, you must first learn to fly before you can attempt to go aloft safely. Nothing short of a thorough mastery of the machine can suffice to give the aviator the ability to do the right thing at the right moment, in the great majority of cases. There will always be occasions when even the most skilled aviator will make errors of judgment and frequently they cost him his life. But this is equally true of every dangerous calling, whether it be running an automobile, driving a locomotive, or doing any of the thousand and one things where the responsibility for his own and other lives is placed in one man's hands and depends to a large extent on his discretion and judgment in cases of emergency, so that there will be fatalities from this cause as long as man continues to fly. This involves the personal equation that must always be reckoned with. Just how many of the accidents that have resulted in the fatalities set forth, have been due to the fallibility of the operator and for how much the design of the current types of machines is responsible, would be hard to say. Fig. 45, for example, which shows H. V. Roe in the act of striking the ground in his triplane, illustrates an accident due to bad design. Methods of control will be improved and simplified and made as nearly "fool-proof" as human ingenuity can accomplish, but experience in other fields has demonstrated unmistakably that they can never be developed to a point where it is impossible to do the wrong thing. With skill at such a premium in callings of responsibility which involve only conditions that have been familiar for years, how much more so must it be in the air about which so little is known? Consequently, the real danger is to be found in the personal equation, just as it is in every other mode of conveyance, despite the fact that it has been perfected to a point which apparently admits of little further development where safeguarding it is concerned.

Obstructions. Obstructions are bound to play a prominent part in accidents to any method of conveyance, but less so in aviation than in any other, as it is only in rising and alighting that this danger

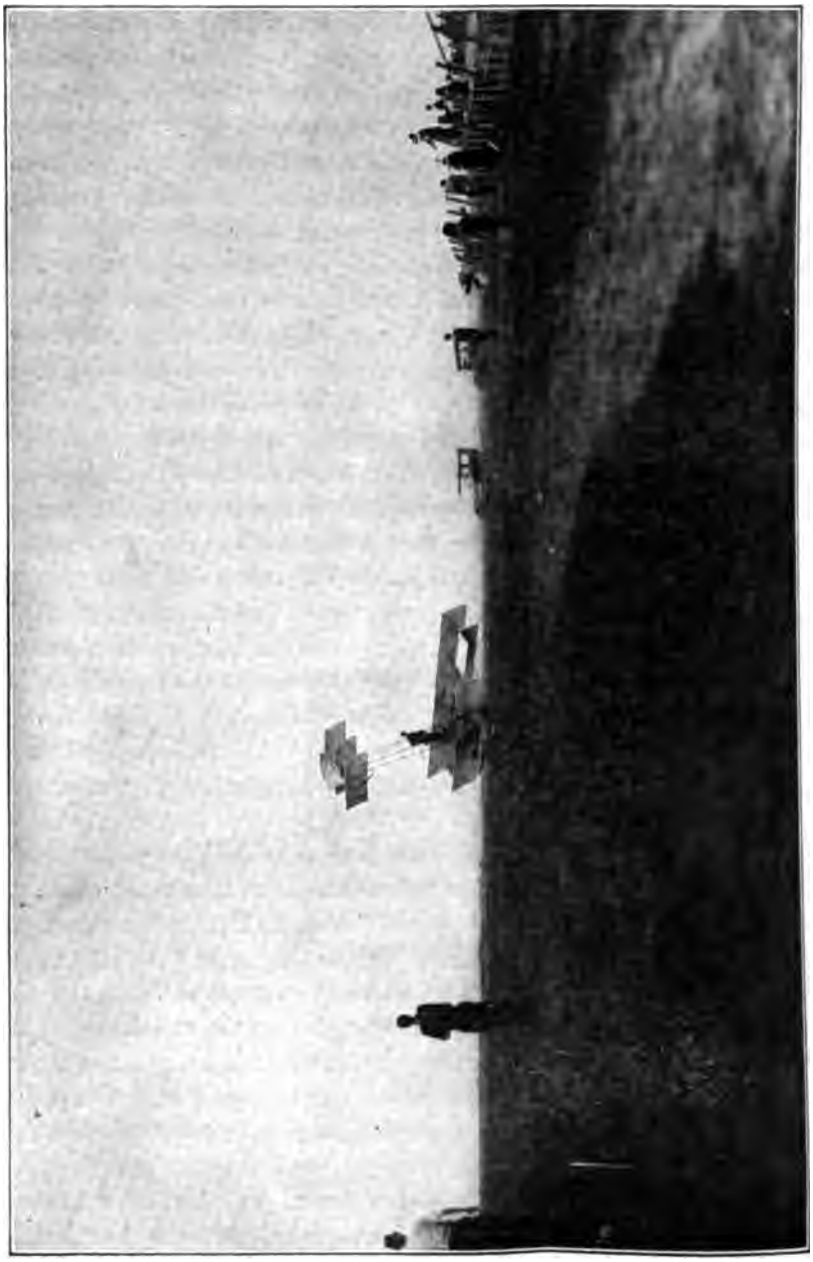

Fig. 45. Roe's Multiplane as it Struck the Ground. An Accident Due to Poor Design

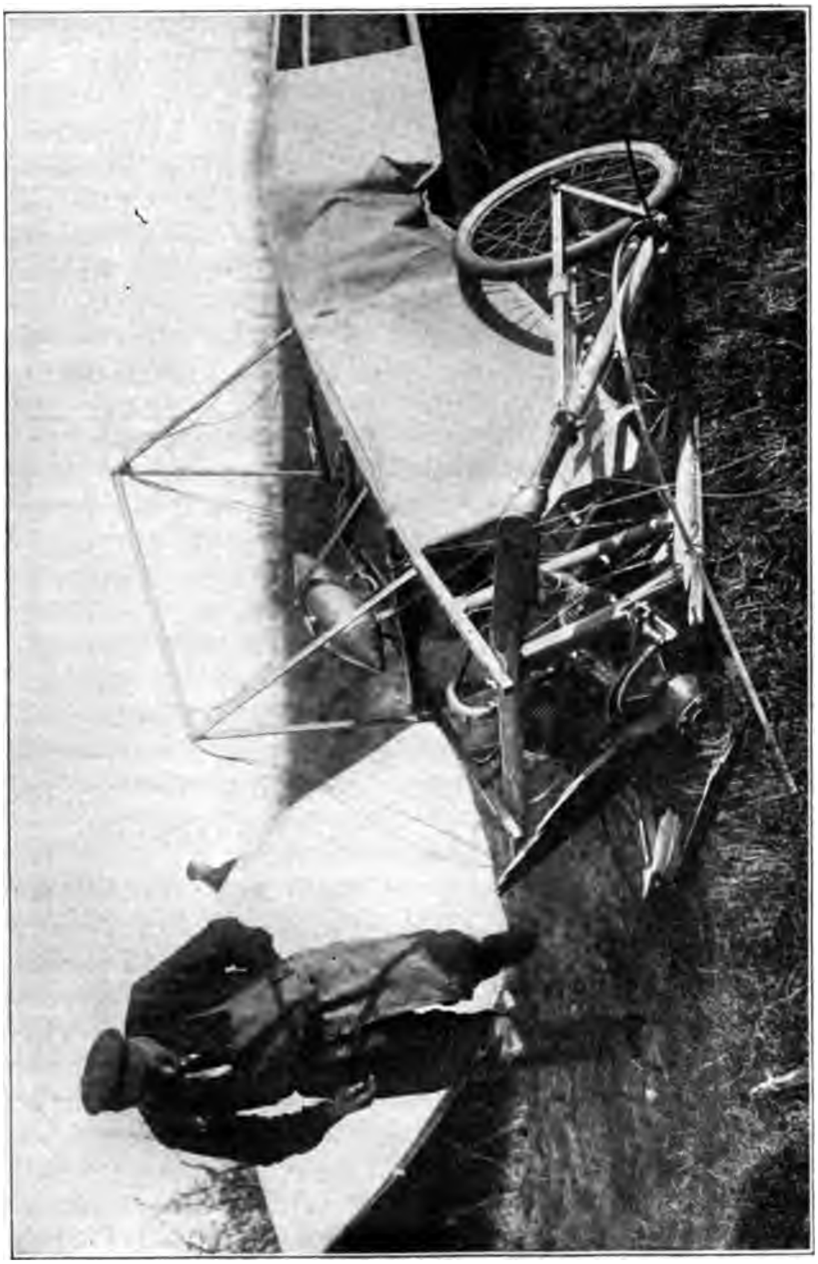

Fig. 46. DeLesseps' Machine after Striking an Obstruction

is present. Of the two fatal accidents ascribed to this cause, one resulted from colliding with an obstruction while running along the ground preparatory to rising, and the other from striking an obstruction in flight, Fig. 46. In view of the numerous cross-country flights that have been made, trips across cities and the like, it is to be marveled at that up to the present writing no fatalities have been caused by what the aviator most dreads when leaving the safety of the open field, that is, being compelled to make a landing through stoppage of the motor, whether from a defection or lack of fuel. While no fatalities have as yet to be put down to this ever-present danger in extended flights, an accident that might have had a fatal termination, occurred to Le Blanc during the competition for the Gordon-Bennett trophy, which was the chief event of the International Meet in October, 1910, at Belmont Park, near New York. Le Blanc and his fellow compatriots who were eligible were all experienced cross-country flyers, the former having won the *Circuit de L'Est*, a race around France, and by far the most ambitious of its kind which had been attempted up to that time. They accordingly protested most vigorously against flying over the American course to compete for the cup which Curtiss had captured at Rheims the year before, owing to the fact that it presented numerous dangerous obstructions in the form of trees and telegraph poles. But as it was impossible to provide any other convenient five-kilometer circuit (3.11 miles) as called for by the conditions, the protest was of no avail. After

Fig. 47. Overturned Monoplane Due to a Start in a Gale

having covered 19 of the 20 laps necessary to complete the distance of 100 kilometers in time that had never been approached before, Le Blanc was compelled to descend through lack of fuel, and as he had not risen more than 80 to 100 feet at any time during the race, this meant coming down the moment the motor stopped. The result was a collision with a telegraph pole, breaking it off and wrecking the monoplane, the aviator fortunately escaping any serious injury. During the same meet Moisant demolished his Bleriot monoplane by trying to start in the face of a high wind, Figs. 47 and 48.

Stopping of Motor. The mere fact that the motor stops does not necessarily mean a disastrous ending to a flight, as is very commonly believed, this having been strikingly illustrated by Brookins' glide to earth from an altitude of 5,000 feet with the motor dead, and Moisant's glide from an even greater height in France. But it does mean a wreck unless a suitable landing place can be reached with the limited ability to control the machine that the aviator has when he can no longer command its power. Motors will undoubtedly become more and more reliable as development progresses, but the human equation—the partly-filled fuel tank, the loose adjustment that is overlooked before starting, and a hundred and one things of a similar nature—will always play their rôle, so that compulsory landing in unsuitable places will always constitute a source of danger as flights become more and more extended.

Fig. 48. View of Moisant Monoplane after a Bad Spill

Breakage of Parts of Aeroplanes. In studying the foregoing table, it can only be a source of satisfaction to the intelligent student and believer in aerial navigation, to note how large a proportion of the accidents is due to the breakage of parts of the machine. This implies a fault in construction, but not in *principle.* It reveals the fact that, in the attempt to secure lightness, strength has sometimes been sacrificed, chiefly through lack of appreciation of the stresses to which the machine is subjected in operation. At a time when weight is regarded almost as the paramount factor by so many builders, it is inevitable that some should err by shaving things too fine. Lightness is an absolute necessity and failure to achieve it in every instance without eliminating the factor of safety has been due more to the crude methods of construction and lack of suitable materials, than any other cause—conditions that are bound to obtain in the early days of any art. Construction is improving rapidly, but progress is bound to be attended with accidents of this nature. The fact that their proportion is greatly diminishing despite the rapidly increasing number of aviators is the best evidence of what is being accomplished. When machines are built with such a high factor of safety in every part that breakage is an almost unheard-of thing, failures from this cause will have been reduced to an unsurpassable minimum.

Failure of the Control Mechanism. Under the general classification B, are included not alone those accidents directly due to breakage of some vital part, but also those instances in which some element of the control, such as the elevator, has become inoperative through jamming. When an accident happens in the air, it takes place so quickly and the machine is so totally wrecked by falling to the ground, that it is usually difficult to determine the exact nature of the cause through a subsequent examination of the parts, so that it can seldom be stated with certainty just what the initial defection consisted of, though it may be regarded as a foregone conclusion that, in the case of experienced aviators who have previously demonstrated their ability to cope with all ordinary emergencies, nothing short of the failure of some vital part could have caused their fall.

This was the case with Johnstone's accident at Denver—an occurrence illustrating another phase of the personal equation that must be taken into consideration when noting the lessons to be learned from a study of accidents and their causes. It is simply the old, old story of familiarity breeding contempt — the miner thawing out sticks of dynamite before an open fire. Due to the rarefied air of Denver, which is at an elevation of more than 5,000 feet, Johnstone had underestimated the braking powers of the air on the machine in landing the day previous and had crashed into a fence, breaking one of the right outermost struts between the supporting planes.

Proper regard for safety should naturally have called for its replacement by an entirely new strut, but conditions at flying meets as at present conducted make quick repairs to damaged machines imperative. The damaged upright was accordingly glued and braced by placing iron rings around it, the rings themselves being held in place by ordinary nails passing through holes in the iron large enough to let the nail head slip through. The vibration of the motor and the straining of the strut in warping the wings caused the nails to work out of the holes, permitting the rings to slide out of place as well. Johnstone was an accomplished aviator, much given to the execution of aerial maneuvers only possible to the skilled flyer of quick and ready judgment. But such performances impose excessive stresses on the supporting planes and their braces, and one of Johnstone's quick turns caused the repaired struts to collapse through the strain of sharply warping the wing tips on that side. He immediately attempted to restore the balance of the machine by bringing the left wing down with the control, then tried to force the twisting on the right side, succeeding momentarily, and a few seconds later losing all control and crashing to the ground. It appeared to demonstrate that even when disabled an aeroplane is not entirely without support, but has more or less buoyancy—something which is really more of an optical illusion than anything else due to underestimating the speed at which a body falls from any great height. Johnstone's accident was the first of its kind, in that he fell from a height of about 800 feet, during the first 500 of which he struggled to regain control of the machine, finally dropping the remaining 300 feet apparently as so much dead weight. It showed in a most striking manner the vital importance of the struts connecting the supporting surfaces of the biplane, any damage to them resulting in the crippling of the balancing devices and the end of all aerial support.

Biplane vs. Monoplane. It requires only a glance at Table III to show that the greater number of accidents have happened to the biplane, yet the latter is generally regarded as the safer of the two. Prior to Delagrange's fatal fall in January, 1910, there had been only four fatalities with modern flying machines: Selfridge and Lefebre were killed in Wright machines, the latter of French manufacture, Ferber lost control of his Voisin biplane, and Fernandez was killed flying a biplane of his own design. In one case at least, that of Lieutenant Selfridge, the accident appears to have been due to the failure of a vital part—the propeller. It has since become customary to cover the tips of propellers for at least a foot or so with fabric tightly fitted and varnished so as to become practically an integral part of the wood. This prevents splintering as well as avoiding the danger of the laminations succumbing to centrifugal force and flying apart. At the extremely high speeds, particularly at which direct-driven propellers are run, the stress imposed on the outer portion of the blades by this force is tremendous. In making any attempt to compare the number of accidents to the biplane and the monoplane, it must also be borne in mind that the former has been in the majority.

Delagrange's accident offers two special features of technical interest. It was the first fatality to happen with the monoplane and was likewise the first fatal accident which appeared to be distinctly due to a failure of the main structure of the machine. For obvious reasons, it is usually difficult to definitely fix the cause of an accident, but in this case there seemed good reason to suppose that the main framing of one of the wings gave way altogether. Curiously enough, Santos-Dumont had an accident the day following from an exactly similar cause, the machine plunging to the ground. But with the good fortune that has attended this experimenter throughout his long aerial career, he was uninjured. It was definitely established that the cause was the fracture of one of the wires taking the upward thrust of the wing. In the case of the biplane, the top and bottom members are both of wood, with wooden struts, the whole being braced with numerous ties of wire. In the monoplane, however, the main spars are trussed to a strut below by a comparatively small number of wires. The structure of each wing is, in fact, very much like the rigging of a sailboat, the main spars taking the place of the mast while the wire stays take that of the shrouds, with this very important difference, that the mast of the boat is provided with a forestay to take the longitudinal pressure when going head to the wind, while the wing of an aeroplane often has no such provision, the longitudinal pressure due to air resistance being taken entirely by the spar.

It is quite possible that this had something to do with Delagrange's accident, as, in the effort to make a new record, his Bleriot had just been fitted with a very much more powerful motor. In fact, double that for which the machine was originally designed, and this was given by the maker as the probable cause of the mishap. As the new motor was of a very light type, the extra weight, if any, was quite a negligible proportion of the total weight of the machine. The vertical stresses on the wings and their supporting wires would, therefore, not be materially increased. But as the more powerful engine drove the wings through the air a great deal faster, the stresses brought upon them by the increased resistance would be substantially augmented and, unless provision were made for this, the factor of safety would be much reduced. Whether the failure of the wing was actually from longitudinal stress or the breaking of a supporting wire, as in Santos-Dumont's case, will never be known, but it is quite clear that the question of ample strength to resist longitudinal stresses should be carefully considered, especially when increasing the power of an existing machine.

The question of the most suitable materials and fastenings for the supporting wires is, moreover, a matter which requires very careful consideration. In the case of the biplane, the wires are so numerous that the failure of one, or even more, may not endanger the whole structure, but those of the monoplane are so few that the breaking of but one may mean the loss of the wing. In this respect, as in others, the conditions are parallel to the mast of the sailboat. It is only reasonable to expect, therefore, that similar materials would be best adapted to the purpose. At present, however, the stays of aeroplane wings are almost invariably solid steel wire, or ribbon, while marine shrouds are always of stranded wire rope, solid wire not having been found satisfactory. Weight for weight, the solid wire will stand a greater strain when tried in a testing machine than will the stranded rope, but practice has always demonstrated that it is not so reliable. The stranded rope never breaks without warning, and sometimes several of its wires may go before the whole gives way. As the breakage of the strands can be easily seen, it is possible to replace a damaged stay before it becomes unsafe. In the case of a single wire, there is nothing to show whether it has deteriorated or not. It seems a doubtful policy to use in an aeroplane what experience has shown not to be good enough for a boat, and stranded wire cables particularly designed for aeronautic use are now being placed on the market in this country.

Record Breaking. Striving after records has undoubtedly proved one of the most prolific causes of accident. What is wanted to make the aeroplane of the greatest practical use is that it should be safe and reliable. The tendency of record-breaking machines is the exact opposite of this, as the weights of all the most essential parts must be cut down to the finest limits possible in order to provide sufficient power and fuel-carrying capacity for the record flight. It is, in fact, generally the case in engineering that the design and materials which will give the best results for a short time are essentially different from those which are the most reliable, and striving after speed records consists simply in disregarding safety and reliability to the greatest extent to which the pilots are willing to risk their necks, and there is no difficulty in getting men to take practically any risk for the substantial rewards offered.

The performance of specially sensational feats in the air is likewise a fertile source of accidents. One noted aviator who has the reputation of being a most conservative and expert operator, while endeavoring to land within a set space, made too sudden a turn, which resulted in the tail of the machine giving way, precipitating him to the ground. In fact, the number of failures resulting from abrupt turns shows conclusively that there is too small a factor of safety in the construction, not because the added weight could not be carried, but because the extreme lightness alone made possible the stunts for which there is always applause or financial reward. It may seem strange to the man whose only interest in aeronautics is that of an observer, that so many should be willing to take such unheard-of chances; that an aeronaut will rise to great heights, knowing in advance that a vital part of his machine has been deranged, or is only temporarily repaired; and that many others will attempt ambitious flights with engines or other parts that have never been tested previously in operation in the air. Many young and inexperienced aviators are not content to thoroughly test out each new part on the ground, or close to it, but must go aloft at once to do their experimenting, with the usual result of such foolhardiness. If in other sports safe conditions were absolutely disregarded in this manner —take football as an instance—the resulting fatalities would not be charged against the sport itself. But aviation is so extremely novel and likewise so mysterious to the uninitiated that this is never taken into consideration.

Excessive Lightness of Machines. If, even at the present early stage of aviation, machines are being made excessively light for purposes of competition, it is time that the contest committees of organizations in charge of meetings formulate rules as to the size of engines, weight of machines, and similar factors, so that accidents will not only be reduced to a minimum, but competition along proper lines will develop types of machines which are useful and not merely racing freaks, as has already been done in the automobile field. Hair-raising performances also should be prohibited, at least until such time as improvements in the construction of machines make it reasonably certain that they are able to withstand the terrific strains imposed upon them in this manner. Suddenly attempting to bring the machine to a horizontal plane after a long dip at an appalling angle is an extremely dangerous maneuver, whether it be taken in the upper air or is one of the now familiar long glides to earth, which require pulling up short when within a few feet of the ground and after the dropping machine has acquired considerable inertia. The aviator is simply staking his life against the ability of the struts and stays to withstand the terrific stresses imposed upon them every time this is done.*

As at present constructed, many of the machines are not sufficiently strong to withstand the utmost in the way of speed and sudden turns which the skilled operator is likely to put on them. They should be made heavier, or of materials providing greatly increased strength with the same weight. That they can be made heavier without seriously damaging their flying ability has been

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*This is exactly what occurred at the Chicago Meet, August 15, 1911, when Badger's Baldwin biplane collapsed at the end of a long dive, causing the death of the aviator.

clearly demonstrated by the numerous flights with one and two passengers, and on one occasion in which three passengers besides the driver were taken up on an ordinary machine. This was likewise tempting fate by overloading, but it served to show the possibilities.

Landings. Then there is a class of accidents for which neither the aviator nor the machine is responsible, as where spectators have crowded on the field, causing the flyers to make altogether too sudden or impromptu landings at angles which would otherwise not be considered for a moment. This, of course, refers solely to exhibition meets, and the comparative immunity of cross-country flights from fatal accidents as compared with the latter, speaks for itself in this respect. In the open, even the novice seems to be able to pick a safe landing, especially if high enough to glide some distance before reaching the ground. This brings out the fact that, as a rule, the machines are

Fig. 49. Monoplane is Liable to Stand on its Head if Landing is Not Properly Made

safer in the air—a large part of the danger lies in making a landing. Starting places are usually smooth, but landing places may be the reverse. When alighting directly against the wind, which is the only safe practice, most of the machines will remain on an even keel until they come to a stop, but the slightest bump or depression, in connection with a side gust of wind, may swerve it around and capsize it, as demonstrated by the illustration of a bad landing by De Lesseps, Fig. 49. This was emphasized by some of the minor accidents at the International Meet near New York. There is no precision or accuracy in the movements of a flying machine when rolling slowly over the ground after the engine has been shut off, and the aviator is, to a certain extent, helpless. The wheels on most machines are placed too near the center and too close together. When an attempt is made to land with the wind on the quarter or side, although the machine may strike the ground safely, owing to the accuracy with which it may be controlled in the air while at speed, it is apt to turn after rolling a short distance and the wind will then easily capsize it, breaking a wing, smashing a propeller, and sometimes injuring the motor or the aviator. Accidents from this cause have been common.

These accidents and collisions with obstructions make plain the fact that brakes are quite as necessary on an aeroplane as on any other vehicle intended to run on the ground. Practically all aeroplanes are fitted with pneumatic tires and ball-bearing wheels and, as there is very little head resistance, they will run a considerable distance after alighting at a speed of 20 to 30 miles an hour. The employment of a brake on the wheels would have averted one of the fatal accidents abroad, as noted in Table III. They would have enabled Johnstone to stop his machine before colliding with the fence surrounding the aviation grounds at Denver, and they would have prevented several minor accidents at various meets, which, though not endangering the aviator in every instance, have often seriously damaged his machine. Every exhibition field is obstructed by fences, posts, buildings, and the like, and to avoid coming in contact with these, as well as with the irrepressible spectator, the aviator should certainly have an effective means of bringing the machine to a standstill when it is running along the ground. How much more so is this necessary for cross-country flying when the choice of a landing place is a difficult matter at best. Ability to come to a stop quickly would make it possible to land in restricted places where only a very limited run along the ground could be had.

Lack of Sufficient Motor Control. Another class of accidents that take place on the ground suggests the necessity for improving the motor control. In alighting, the motor is usually stopped by cutting off the ignition—ordinarily by grounding or short-circuiting. Throttling to stop appears to be seldom resorted to, but as several instances have occurred in which the aviator found it impossible to cut off the ignition, resulting in a collision with another machine or a building, it is evident that the control should be arranged so that both methods could be employed. With the increasing use of air-cooled motors that may continue to run through self-ignition after the spark has been cut off, this is more necessary than ever.

While it has been demonstrated that the stoppage of the motor does not necessarily involve a fall, most aviators will naturally prefer to command the assistance of the motor at all times, and in the case of motors using a carbureter this should be jacketed either from the cooling water or the exhaust, and means provided for increasing the air supply to prevent the motor stopping at a great height owing to the cold and the rarefied air. The reasons for this have been gone into more at length under the heading of "Altitude." With these and similar improvements that will be suggested by experience and further accidents, there appears to be no reason why aviation can not be made as safe as the personal equation will permit it to be. There will always be reckless flyers. Ignorance and incompetence can not be altogether eliminated any more than they can in sailing, hunting, or any other sport. The annual hunting fatalities from these causes in this country alone make a total beside which the aggregate of four years in aviation the world over, is but an insignificant fraction.

Parachute Garment as a Safeguard. To save as many as possible of these reckless ones from themselves, so to speak, a parachute garment has been devised to ease the shock of the fall. It will be recalled that Voisin would not fly in his biplane until he had provided himself with a heavily-padded helmet, somewhat on the order of the football headpiece. But neither a padded headpiece nor padded clothing would avail much against a fall of any kind from an aeroplane; hence, the parachute garment. Its object is not to take the shock of a fall, as are the pads, nor is it to prevent a fall, but to reduce the rate of drop by interposing sufficient air resistance to make the fall safe. This new parachute is in the form of a loose flowing garment, securely fastened to the body and fitted over a framework carried on the aviator's back. The lower ends of the garment are secured to the ankles. The arrangement is such that when the aviator throws out his arms, the garment is extended somewhat in umbrella or parachute form, thus creating sufficient resistance to prevent too rapid a descent. Experiments have been made with this parachute dress in which the wearer has jumped from buildings, cliffs, and other heights, and the garment has assumed its rôle of parachute at once, permitting a safe and easy descent.

Study of Stresses in Fancy Flying. To sum up, it will be seen that the most prolific cause of fatalities is the personal equation. Of all the many dangers encountered in aeroplaning, one of the most clearly defined, as well as one of the most seductive, results from fancy flying: from wheeling round sharp, horizontal curves; from conic spiraling; from cascading, swooping, and undulating in vertical plane curves, popularly dubbed "stunts." These are forms of flying in which aviators constantly vie with one another. They frequently result in imposing stresses upon the machine which are far beyond its capacity to withstand. The danger is particularly alluring to reckless young aviators engaged in public exhibitions. The death of St. Croix Johnstone, at the Chicago Meet in the summer of 1911, affords a typical illustration of what may be expected as the result of such performances. Nevertheless, partly because they do not adequately appreciate the risk, and largely, no doubt, because of the liberal applause accorded by an admiring throng which also fails to realize the hazardous nature of the fascinating maneuvers, there will doubtless always be aviators to undertake such feats.

Singularly enough, the exact magnitude of such hazards, or more accurately, the extent of the increased stress in the machine, though beyond even the approximate guess of the aviator, is capable of nice computation in terms of the speed and curvature of flight. During an exhibition meet in Washington, D. C., during the summer of 1911, Glenn H. Curtiss found difficulty in restraining one of his young pupils from executing various hair-raising maneuvers. He would plunge from a great elevation to acquire the utmost speed, then suddenly rebound and shoot far aloft. He would undulate about the field, and on turns would bank the machine until the wings appeared to stand vertical. Curtiss solemnly warned the young aviator and earnestly restrained him, pointing out the dangers of sweeping sharp curves at high speed, of swooping at such dangerous angles, and the like. Curtiss then turned to A. F. Zahm and expressed the wish that someone would determine exactly the amount of the added stress in curvilinear flight. The following, published by Zahm, in the *Scientific American,* gives the method of calculating this:

> When a body pursues a curvilinear path in space, the centripetal force urging it at any instant may be expressed by the equation
>
> $$Fn = m\frac{V_2}{R} \text{ (absolute units)}$$
>
> $$= \frac{m}{g}\,\frac{V^2}{R} \text{ (gravitational units)}$$
>
> in which Fn is the centripetal force, m the mass of the body, V its velocity, and R the instantaneous radius of curvature of the path followed by its center of mass. Since the mass may be regarded as constant for any short period, the equation may be expressed by the following simple law:
>
> *The centripetal force varies directly as the square of the velocity of flight and inversely as the instantaneous radius of the curvature of its path.*

In applying the above equation to compute the stress in an aeroplane of given mass m, we may assume a series of values for V and R, compute the corresponding values for Fn, and tabulate the results for reference. Table IV has been obtained in this manner. It may be noted that on substituting in the equation, V is taken as representing miles per hour, R as feet, and g as 22 miles an hour, in order to simplify the figuring, this being 32.1 feet per second. The table shows at a glance the centripetal force acting on an aeroplane to be a fractional part of the gravitational force, or weight of the machine and its load. For example, if the aviator is rounding a curve of 300 feet radius at 60 miles per hour, the centripetal force is 0.55 of the total weight. At the excessively high speed of 100 miles per hour and the extremely short radius of 100 feet, the centripetal force would be 4.55 times the weight of the moving mass. The pilot would then feel heavier on his seat than he would sitting still with a man of his own weight on either shoulder. For speeds below 60 miles per hour and radii of curvature above 500 feet, the centripetal force is less than one third of the weight. The table gives values for speeds of 30 to 100 miles per hour, by increments of 10 miles, and for

TABLE IV

Centripetal Force Acting on Aeroplane at Various Speeds and Curvatures of Flight

(V) Velocity or Speed of Aeroplane	(R) Radius of Curvature in Feet 100	200	300	400	500
Miles per hour	Weight	Weight	Weight	Weight	Weight
30	0.41	0.20	0.14	0.10	0.08
40	0.73	0.36	0.24	0.18	0.15
50	1.14	0.57	0.38	0.28	0.23
60	1.64	0.82	0.55	0.41	0.33
70	2.23	1.11	0.74	0.56	0.45
80	2.91	1.45	0.97	0.73	0.58
90	3.68	1.84	1.23	0.92	0.74
100	4.55	2.27	1.52	1.14	0.91

radii of curvature of 100 to 500 feet, by increments of 100 feet, so that intermediate speeds and radii may readily be calculated.

The entire stress on the aeroplane in horizontal flight, being substantially the resultant of the total weight and the centripetal force, can readily be figured by compounding them. Thus in horizontal wheeling, the resultant force as shown in the diagram, Fig. 50, is approximately

$$F=\sqrt{Fn^2+W^2}$$

In swooping, or undulating in a vertical plane, the resultant force at the bottom of the curve has its maximum value

$$F=(Fn+W)$$

and at any other part of the vertical path, it has a more complex though smaller value, which need not be given in detail.

It is obvious that the greatest stress on the machine occurs at the bottom of a swoop, if the machine be made to rebound on a sharp curve. The total force $(Fn+W)$ sustained at this point may be found from the table, if V and R be known, simply by adding 1 to the figures given, then multiplying by the weight of the machine. For example, if the speed be 90 miles per hour and the radius of

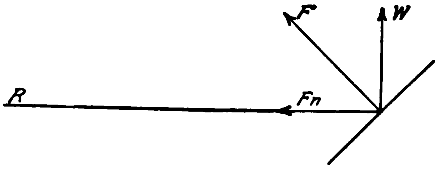

Fig. 50. Force Diagram in Horizontal Wheeling

curvature 200 feet, the total force on the sustaining surface would be 2.84 times the total weight of the machine. In this case, the stress on all parts of the framing would be 2.84 times its value in level flight, when only the weight has to be sustained. The pilot would feel nearly three times his usual weight.

From the foregoing, it is apparent that in ordinary banking at moderate speeds on moderate curves, the additional stress due to centripetal force is usually well below that due to the weight of the machine, and that in violent flying, the added stress may considerably exceed that due to the weight of the machine and may accordingly be dangerous, unless the aeroplane be constructed with a specially high factor of safety. But there is nothing in the results here obtained that seems to make sharp curving and swooping prohibitive. If the framing of the machine be given an extra factor of safety, at the expense perhaps of endurance and speed, it may be made practically unbreakable by such maneuvers, and still afford to the pilot and spectators alike all the pleasures of fantastic flying.

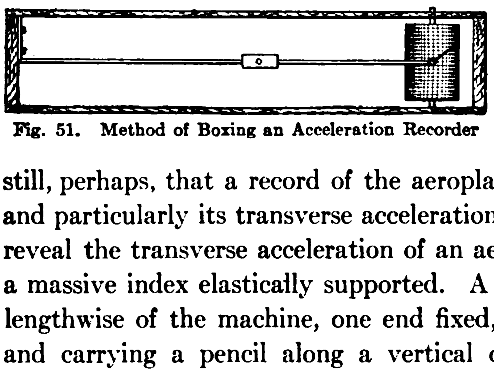

Fig. 51. Method of Boxing an Acceleration Recorder

Methods of Making Tests. In order to obtain actual data for the fluctuations of stress in an aeroplane in varied flying, it is suggested that the stress or strain of some tension or compression member of the machine be recorded when in action; or simpler still, perhaps, that a record of the aeroplane's acceleration be taken and particularly its transverse acceleration. A very simple device to reveal the transverse acceleration of an aeroplane in flight would be a massive index elastically supported. A lath or flat bar stretching lengthwise of the machine, one end fixed, the other free to vibrate, and carrying a pencil along a vertical chronograph drum, would serve the purpose. This could be protected from the wind by a housing as shown in the sketch, Fig. 51.

An adjustable sliding weight could be set to increase or diminish the amplitude of the tracing, and an aerial or liquid damper could be added to smooth the tracing. The zero line would be midway between the tracings made on the drum by the stationary instrument when resting alternately in its normal position and upside down; the distance between this zero line to the actual tracing of the stationary instrument would be proportional to the aeroplane stresses in level, rectilinear flight; while in level flight on a curve, either horizontal or vertical, the deviation of the mean tracing from the zero line would indicate the actual stress during such accelerated flight. Of course, the drum could be omitted and a simple scale put in its place, so that the pilot could observe the mean excursion of the pencil or pointer from instant to instant; also, the damper of such excursion could be adjusted to any amount in the proposed instrument if the vibrating lath fitted its encasing box closely with an adjustable passage for the air as it moved to and fro; or if light damping wings were added to the lath, or flat pencil bar.

Another method would be to obtain by instantaneous photography the position of the centroid of the aeroplane at a number of successive instants, from which could be determined its speed and path, or V and R of the first equation, by which data, therefore, the stress could be read from Table IV.

Perhaps the simplest plan would be to add an acceleration penholder, with its spring and damper, to any recording drum the aeroplane may carry for recording air pressure, temperature, speed, and so forth. Indeed, all such records could be taken on a single drum.

A score of devices, more or less simple, but suitable for revealing the varying stress in an aeroplane, will occur to any engineer who may give the subject attention. And it is desirable in the interests both of aeroplane design and of prudent manipulation that someone obtain roughly accurate data for the stresses developed in actual flight.

Increment of Speed in Driving. It is commonly supposed by aviators that the *increment* of speed due to driving is very prodigious. An easy formula will determine the major limit of such speed increment. If the initial and natural speed of the aeroplane be v, and the change of level in diving be h, while the speed at the end of the dive be V, the minimum change of level necessary to acquire any increment of speed, $V-v$, may be found from the equation

$$h=\frac{(V-v)}{2g}$$

If, as before, g be taken as 22 miles per hour, the equation reduces

TABLE V

Minimum Change of Level Necessary to Produce Various Speed Increments

Natural Speed v of the Aeroplane	Increments of Speed $V-v$		
	Miles per hour, 10	Miles per hour, 20	Miles per hour, 30
Miles per hour	Feet	Feet	Feet
30	23.3	53.3	90.0
40	30.0	66.7	110.0
50	36.7	80.0	130.0
60	43.3	93.3	150.0
70	50.0	106.7	170.0

to the convenient formula

$$h=\frac{(V-v)}{30}$$

in which V and v are taken in miles per hour. Assuming various values for V and v, Table V has been found for the corresponding values of h in feet: For example, if the natural speed of the aeroplane in level flight be 50 miles per hour, and the aviator wishes to increase the speed by 20 miles per hour, he must dive at least 80 feet, assuming that the aeroplane falls freely, like a body *in vacuo*, or that its propeller overcomes the air resistance completely; otherwise the fall must be rather more than 80 feet.

It has been suggested that a contest be arranged to determine which aviator could dive most swiftly and rebound most suddenly, the prize going to the one who should stress his machine most as indicated by the accelerograph above proposed. But to avoid danger, the contest would have to be supervised by competent experimentalists, and would be best conducted over water. It is safe to say that more than one well-known aeroplane would be denied entry in such a contest because of lack of a sufficient factor of safety in its construction.

Dirigible Accidents. Because its wrecks are spectacular and the loss involved tremendous, the dirigible has probably earned an undeserved reputation, though it must be admitted that the big airships have come to grief with surprising regularity. The fact must be noted, however, that when an aeroplane is wrecked, the aviator seldom escapes with his life, while the spectators' lives are endangered to an even greater extent, whereas in the case of the dirigible, the loss is simply financial, both the crew and passengers usually escaping without a scratch. This is largely due to the fact that the majority of accidents to dirigibles have happened on the ground, and have been caused by lack of facilities for properly handling or "docking" the huge gas bag. Of course, lack of flotation or an accident to the motors, or both combined, have brought two of the numerous Zeppelins to earth in a very hazardous manner, though no one was killed, while four French army officers lost their lives in the Republique disaster, the exact cause of which was never definitely ascertained. This was likewise the case with Erbsloeh and his companion who were dropped from the sky, their airship having taken fire. It was thought that ignition was caused by atmospheric electricity, in this instance.

By far the great majority of later dirigible accidents have been due solely to the crude methods of handling the airships on the ground, and the frequency with which these have occurred should certainly have been responsible for the adoption of improvements in this respect at an earlier day.

For instance, the Morning Post, a big Lebaudy type bought for English use, had the envelope ripped open by an iron girder projecting from its shed. Repairs took several months, and at the end of the first trial thereafter, the ship was again wrecked in landing. A company of soldiers failed to hold the big craft and it drifted broadside into a clump of trees, hopelessly wrecking it. In attempting to dock the Deutschland I, 200 men were unable to hold it down, a heavy gust of wind catching the big airship and pounding it down on top of a wind break that had been specially erected at the entrance of the shed for protection. A similar accident happened to the big Parseval, a violent gust of wind casting it against the shed and tearing such a hole in the envelope that the gas rushed out and the car dropped 30 feet to the ground. The big British naval dirigible of the rigid type, the Mayfly, was broken in half in attempting to take it out of the shed the first time. A cross wind was blowing and the gas bag of one of the central sections was torn, deflating it and showing in a striking manner that the solidity of a rigid dirigible results chiefly from the aerostatic pressure of the gas in its various compartments. Without the gas lift, a rigid frame is so in reality only for certain limited distances, as was shown by the total collapse of the Mayfly's frame after having been subjected to the opposed leverage of the parts on either side of the original break. This, of course, was an error in design, as the frame of a rigid dirigible should certainly not be so weak in itself as to collapse upon the deflation of a single one of the central compartments. The incident on the trip of the Zeppelin III to Berlin, in 1909, when the flying blades of a broken propeller pierced the hull without causing an accident, shows how much resistance it may offer.

AMATEUR AVIATORS

It will probably come as a surprise to the average reader to learn that at the end of 1910, there were more than a thousand amateur aviators in this country, though all the flights which form the subject of newspaper reports have been the work of not more than a dozen flyers and doubtless half the population has not as yet seen an aeroplane in flight. The desire to fly, whether it be to satisfy one's desire to soar above the world in seeming defiance of natural laws, or merely to obtain the financial reward that is won by successful flight, attracts a great many from all stations and walks of life. This is particularly true among older boys who look on aviation as an advanced form of kite-flying. An example of rather serious work along this line may be cited of two high school boys of Chicago, Harold Turner and Fred Croll, who built a monoplane weighing 125 pounds, Fig. 52. This machine, although too small for a motor, was equipped with rudder and other operating planes and levers, the elevating plane and ailerons being automatically operated by an electrical device. On one of its flights the machine, carrying a 120-pound operator, was started and propelled by attaching it to an automobile; it rose to a height of 15 feet, and remained in the air 43 seconds.

Contrary to all precedent, the average amateur is bent upon achieving what the skilled professional considers as beyond even his talent and resources—that of building his own flying machine. With every other mechanical vehicle, the amateur learns to drive first and the majority are content with that achievement—for example, very few chauffeurs have any great ambition to build their own automobiles. With flying machines (one of the most difficult of mechanical contrivances), nearly all amateurs want to construct new types for themselves and all confidently expect to fly with no more knowledge than that gained in constructing them. We all have to be apprentices before becoming masters, so all aviators necessarily have to be learners and "grass cutters" before being professionals. Charles K. Hamilton was an exception, but he was already an expert pilot of dirigible balloons, and he did not try to build his own aeroplane. Willard, Mars, and Ely, all Curtiss pupils, flew after a very short training, but they did not attempt to construct aeroplanes for themselves. This is also true of Clifford B. Harmon, the champion amateur.

Fig. 52. What an Amateur Aviator Can Do in Building an Aeroplane

Classes of Amateurs. *Inventors.* Generally speaking, amateurs are of two classes. Those of *the first class* believe they have conceived some entirely new system or invention, or an improvement on some machine that has previously proved a failure; they think they have discovered the secret which other inventors who preceded them failed to grasp. They expend their meager capital in trying to realize high hopes. A comparatively small number ever get as far as completing the machine and one trial on the field is usually sufficient to put a quietus on those who do, as it is disappointing, to say the least, to see the result of a number of months' work undone in a twinkling without the machine having shown the least disposition or ability to get off terra firma.

Would-Be Performers. The second class finds its chief incentive in the munificent reward to be gained with what appears to be comparatively little effort or expenditure, and the amateur who is seeking financial returns has no alternative except to build his own machine, or enter either the Wright or Curtiss school of flying and secure a berth with one of these companies.

Wright and Curtiss Patents. This is the result of conditions at present obtaining in the field of aviation. The only generally successful types of American aeroplanes are the Wright and Curtiss, and the acquirement of a biplane of either type means the expenditure of at least $5,000 for the machine alone, and they are sold only to individuals on the express condition that the machines are not to be used for exhibition or as a means of profit to the owner. The manufacturers have expert flyers of their own who attend meets and fairs throughout the country. It would make their monopoly impossible to allow outsiders to fly their aeroplanes publicly or to exhibit them. By this restriction the price of the machines is kept up and large returns are gained by exhibitions and flying.

To break this monopoly by importing European machines is not possible. All the successful aeroplanes made abroad such as the Farman, Cody, and Sommer biplanes; and the Bleriot, Antoinette, and Grade monoplanes are fitted with devices of control or stability, or both, covered by the Wright patents and can not be flown in this country without legal trouble. The numerous foreign aviators who brought over their machines in the fall of 1910 to compete at the International Meet, did so only on being granted a concession by the Wright Company to the effect that they would not be considered as infringers and sued. Similar arrangements were made at subsequent meets and this handicap will always be present where foreign machines are used.

Evasion by Invention of New Types. But when he thinks of the unprecedented sums paid professionals for simply exhibiting their machines and making short flights, the amateur is anxious to obtain a share of the profits. No thought is given the fact that were he and all his kind permitted to fly, the achievement would soon be commonplace and the aviator's golden age would be over. There are accordingly hundreds of would-be aviators in this country today who are striving to evade the Wright basic patents by either devising entirely new types of aeroplanes, or by inventing new methods of control and stability that will not infringe. Others, reasoning that the old aeroplanes built before the advent of the Wright machine cannot be held as infringements owing to priority, propose to develop Maxim, Langley, and Ader machines, though the dictum in the New York Court of Appeals decision referred to under the head of "Legal Status of Wright Patent," which states that a prior machine which *had never been known to fly* would not be considered an anticipation of a modern successful machine, may prove a stumbling block in their case as well. Thus, a round of the workshops of these enthusiasts reveals a host of heavier-than-air machines of every conceivable type and shape, every one of which, according to its builder, is *an aeroplane that will fly*. Mineola and Garden City, Long Island, harbor a score of these little shops the year round, but the same scenes are being enacted on a smaller scale in almost every state in the Union, and particularly in California, Ohio, Kansas, Massachusetts, and Arizona, in addition to which there are many who are carrying their experiments on in secret. Each believes deep in his heart that he will succeed where a master failed.

"Maxim failed with this type of machine," quotes one. "How did he expect to fly when his control was not proportionate to the machine's lift capacity?" Seemingly, nobody ever thought of that and our friend will make a fortune by going Maxim one better, but he does not. After months of labor and a great deal of expense he finds that some unforeseen difficulty develops which keeps his machine to earth as if it were part and parcel of it. Another has conceived a type of monoplane that is entirely new—different from any existing type—and as the latter are all foreign, he prides himself on having developed a monoplane that will be entirely American—the first and only American monoplane. Theoretically, it is a wonder; mechanically it is correct; and it speeds over the turf with surprising velocity; but when the elevating rudder is operated to make the machine rise, it balks and plunges head first into the ground. Again and again, the propeller and other broken parts are replaced at no small expense; again and again the inventor goes over every part of the machinery and computes the dimensions of the supporting surface to see if it all corresponds with the formula of his special theory. But time after time, the aeroplane acts like a jumping frog and lands head first. At last, its builder becomes convinced that there is something radically wrong and begins to depart from his original plans, involving changes that simply mean a waste of effort and money, since the inventor does not himself know what he is trying to correct and no one else knows better than he what the trouble is.

Evasion by Acquiring European Types. Others still, realizing from the foregoing experiences that it is almost impossible to construct an entirely new type of aeroplane off-hand, acquire European types and propose to fit them with new control and stability devices, such as are not covered by the Wright patents. So far, none has succeeded. Somehow, the Wrights seem to have covered all the conceivable working devices for control and stability, and the numerous attempts have accordingly resulted in failure. Undoubtedly, some of these aeroplanes built by amateurs may really be capable of flight; but how is the inventor to know it when he lacks the ability to operate it? To know how to fly an aeroplane is a condition precedent to success in the field of aviation that can not be met by building of a machine. The beginner is thus badly handicapped. Even though his machine may embody the elements essential to successful flight, he may never be able to establish the fact, since his first blundering attempt or two frequently ends by wrecking the machine, and many have neither the means nor the stamina to persevere further after a few bad wrecks, involving weeks and weeks of rebuilding each time. He can not engage an expert to fly his machine for him, as the expert's time per minute figures out a price that makes him gasp, and even at that the expert professional's time is pretty much all taken. Furthermore, very few would run the risk of attempting to fly an untried aeroplane—they have more to lose through accidental injury than the builder has through the failure of his theories.

And so it is with most inventors. They may have conceived something really good, but it is not complete, and an aeroplane is hardly worth its weight as junk unless it is. Hundreds of patents are taken out every year on devices to be used on heavier-than-air machines; inventors by scores make daily rounds trying to interest financiers in some seemingly wonderful mechanical scheme, and dozens of companies are organized each year to exploit some especially promising inventions. Numbers of aeroplanes are constructed and hailed as marvels, but, somehow, when a successful flight is made by an amateur it is always with some standard aeroplane, either of the Curtiss or Farman types, and mostly the former. In fact, the Curtiss has become a favorite with the amateur since the Federal court refused to sustain the granting of a preliminary injunction in favor of the Wright Company against Glenn H. Curtiss. It is accordingly being taken for granted in general that the outcome of the Wright vs. Curtiss litigation will be to declare the Curtiss machine non-infringing. Should it be the other way about, there will certainly be gloom and despair in the amateur camps throughout the country. However, neither the Wrights nor Curtiss impose any restriction upon the building of machines of their types for experimental purposes, so that the amateur who wishes to copy them may safely do so, provided no attempt be made to employ the machine for purposes of public exhibition or financial gain.

VIEW AT ONE OF THE FRENCH AVIATION GROUNDS SHOWING THE HANGARS RANGED ALONG THE EDGES OF THE FIELD

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AVIATION AND ITS FUTURE

DIRIGIBLE VS. AEROPLANE

While interest, to a great extent, is monopolized by the achievements of the aeroplane, opinion is still more or less divided as to the merits of the two methods of navigating the air—the lighter-than-air (the dirigible) or the heavier-than-air (the aeroplane). Though greatly in the minority, those who contend for the advantages of the dirigible are none the less convinced that, in the final analysis, it will be the airship rather than the flying machine which will reign supreme. From this standpoint, the aeroplane is regarded as a mere scientific toy of rather doubtful utility. The advocates of the flying machine, on the other hand, look upon the dirigible as a huge, unwieldy, and prohibitively costly construction, the futility of which as a successful means of navigating the air will be fully realized by reason of the development of the aeroplane within the next few years. Between these wholly irreconcilable opinions, there is a middle ground taken by those who regard both as being of value in their particular spheres, and who think further that both will endure and develop contemporaneously. By briefly summarizing the advantages and disadvantages of each, the reader will be given an opportunity to judge for himself.

Dirigible. *Advantages.* One of the chief advantages claimed for dirigibles is their ability to take aloft comparatively heavy loads—weights far beyond the capacity of the largest aeroplanes so far constructed. This great carrying capacity permits of transporting large quantities of supplies and fuel and a large crew, with the added advantage of permitting the latter a certain range of movement about the airship while it is in flight—the aeroplanist or his passenger naturally can not stir from their seats. But of greater value than this—particularly for military purposes, to which the dirigible is almost wholly adapted at present—is its ability to remain motionless over the field of action in a calm, or by using its engines to coun-

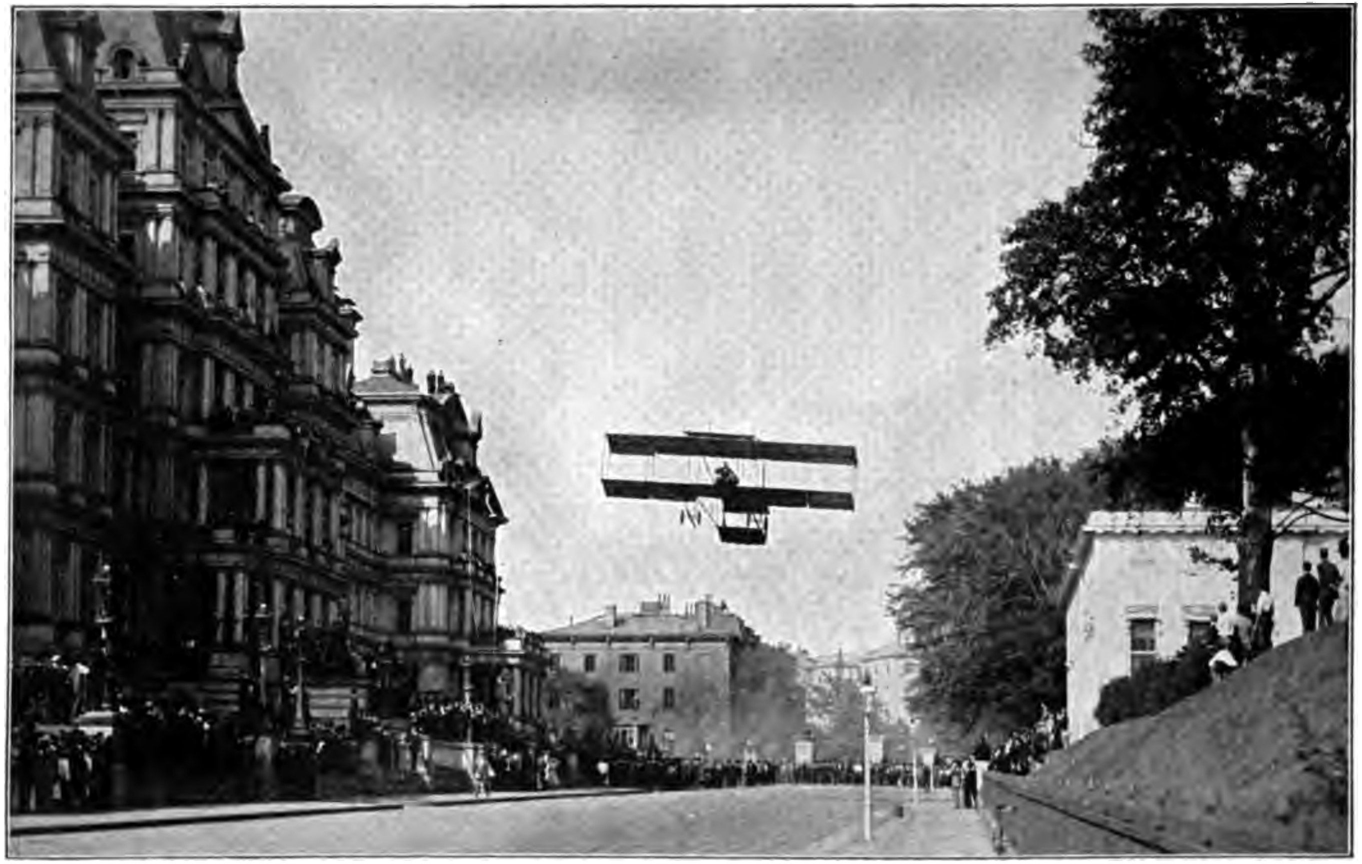

Fig. 1. Claude Grahame White Landing in the Streets of Washington, D. C. An Example of an Aeroplane's Ability to Land or Ascend under Almost Any Conditions

teract a head wind which is within its capacity to resist. Moreover, it is capable of remaining aloft and of traveling with the wind even after its fuel supply is exhausted, and in fair weather it can keep to the air for a much longer period than the aeroplane.

Disadvantages. In the first place, the initial cost of building a dirigible of sufficient size to be of any practical use is so great as to limit its utilization largely to military operations, though a number of dirigibles are being built in Germany by commercial companies for passenger carrying. Few but national governments can afford to build dirigibles. Wellman's ill-fated America, which was small as compared with the military dirigibles of the European governments, cost something like $100,000 to build and equip. Its maintenance is even more costly. The temporary shed to house the America cost $10,000 to erect and $5,000 was spent in inflating the airship once. To propel it, using full power, about 200 gallons of gasoline a day was necessary, with a proportionately large supply of oil. As its speed was low, there would be frequent occasions when the engines would have to be run at their full capacity, simply to prevent it from being carried away by the wind, while there would also be a number of days in the year when it could not safely be taken out of the shed.

To erect a permanent building to shelter one of the large European military dirigibles involves an outlay sufficient to pay for a whole fleet of aeroplanes, and the huge gas bag is never safe outside of its home. While an aeroplane can land on a city street and rise again, Fig. 1, nothing short of a twenty-acre field provides a safe landing place for a dirigible, and the operation is a delicate one even under the most favorable conditions, so much so, that the shed to house the various Zeppelin airships was anchored at first on Lake Constance in order that the dirigible always might enter it against the wind. In view of the great expense involved in providing accommodation for it, the airship is usually compelled to operate from a limited number of fixed bases, to one of which it must return. In case a high wind should spring up when it is aloft, it is equally dangerous to stay in the air or to attempt to land, and it may frequently happen that the force of the wind is so great that the airship can not reach its base at all, or it is blown away from its landing place before the numerous attendants necessary can get it under shelter. This last has happened to French military airships on two occasions, while the Zeppelin dirigibles that have come to grief through being blown to pieces against the ground form a striking illustration of one of the chief dangers to which the tremendously unwieldy apparatus has been subject, but which is now greatly reduced by improved methods of handling.

Aloft, it is surrounded by perils, both from within and without. The close proximity of such a huge quantity of highly inflammable gas to the gasoline engines or other sources of fire renders its operation risky, to say the least, while it is equally exposed to fire or explosion through being out in an electrical storm, it being the general consensus of opinion that lightning, or an electrical discharge caused by the high difference of potential between the atmosphere and the gas bag and metal parts of the airship, caused the explosion which ended the lives of Oscar Erbsloh and his five companions in one of the German military airships in the summer of 1910. As explained under "Wireless on Aeroplane and Airship," it is not necessary that the airship itself should be actually struck by lightning to bring about this discharge, although it offers a powerful attraction; its mere presence at a height where the atmosphere is heavily charged, being sufficient to create electrical discharges capable of setting fire to the gas or to the envelope.

Mention has already been made of the fact that to be of any use, the dirigible must be planned on an enormous scale, with a correspondingly disproportionate increase in the amount of gas required to inflate it and the power needed to drive it. Consequently, it has been found impossible to attain speeds in excess of 43 miles an hour, and only one airship at present in use abroad is capable of going that fast. Even with the most impermeable fabrics that can be manufactured there is more or less leakage of gas, but more serious than this by far is the loss attendant upon ascending and descending. Skillful and rapid manipulation is frequently necessary to prevent rising suddenly to great heights through temperature changes, which occasions the loss of considerable hydrogen in order to return to earth again, while cloudy weather and particularly the sudden advent of rain brings about an alarming contraction in the envelope. Reference to Wellman's experiences with the America will reveal how precarious an undertaking the keeping an airship aloft over night is, the loss of lifting power through the drop in the temperature being so great as to seriously imperil its safety. Add to this the necessity of returning to its base of operation in order to be safely housed against the wind when on the ground, and it will be apparent that the dirigible is very much of a fairweather craft, though the German army dirigibles are said to be used frequently for night trips.

Large Radius of Action. To offset this formidable list of weaknesses and disadvantages, it may be pointed out that the airship has accomplished some wonderful trips, seemingly all the more wonderful because at the time of their execution there were no other performances to compare them with. But upon referring to the circumstances under which they have been carried out, it will be found that they were usually under the most favorable conditions. The weather was favorable, the wind never in excess of 35 miles an hour, and the entire trip was of necessity completed during daylight, usually between dawn and 8 P.M., when the temperature range is not so great as seriously to affect the lifting capacity. While capable of carrying aloft a greater number than can as yet be approached by the aeroplane, it is likewise necessary to carry a much greater crew, so that the actual passenger-carrying capacity is much less than that of the aeroplane in proportion to size. Whether the latter has, as its sole freight, the aviator himself, or carries eight passengers, as in the case of the Bleriot "bus," the entire control is centered in one man. However, the dirigible has the inestimable advantage of providing direct access to the motors, so that they can be restarted, and the further advantage of being able to stop its motors and still remain aloft.

Aeroplane. *Cost.* In summarizing the advantages and disadvantages of the aeroplane in a similar manner, the first consideration is naturally that of *cost*—both initial and subsequent. Taking the cost of a good two-man machine as $5,000, the price at which the Wright biplane lists in this country, it will be seen that 100 of these machines can be placed in the field for the price of but a single Zeppelin dirigible, which is said to cost $500,000. The expense of the initial inflation of such an airship represents the equivalent of another aeroplane, while its bill for fuel would keep a great many of them in the air, and the cost of a shed for housing it would mean probably ten more, as a huge permanent building of the size required involves close to an outlay of $50,000. On the question of expense, therefore, the dirigible is hopelessly at a disadvantage, and as its value as to carrying power is in direct proportion to its size, this must always be the case.

Speed. No comparison is possible where *speed* is concerned for the slowest aeroplane travels as fast or faster than the most speedy dirigible—about 43 miles an hour—while speeds in excess of 99 miles an hour already have been reached by the aeroplane with every prospect that, with the developments of the next few years, the speed of flight will be materially increased.

Strategic Advantages. Any strategic advantages the use of the dirigible might possess vanish completely in the face of such superiority in speed, which means a proportionately greater ease of maneuvering. There appears to be no reason why one $5,000 aeroplane could not easily be the means of destroying a $500,000 dirigible in time of war, while if beset by a fleet of these high-speed flyers, its destruction would be inevitable. The huge gas bag of an airship forms a mark that would be difficult to miss and even small arm fire would quickly destroy the value of the envelope as a supporting medium. The wings of an aeroplane, on the other hand, could be riddled with bullets without seriously impairing its ability to stay aloft. Now that the only limit to altitude flights is the aviator's endurance, there could be no possible escape for the dirigible. Although the latter, by the sudden release of ballast, can shoot up to great heights, the aeroplane can rapidly follow, as shown by Johnstone's flight to a height of more than 9,000 feet in a little over 25 minutes, and the crew of the dirigible is quite as susceptible to the physiological effects of the sudden change of barometric pressure as is the operator of an aeroplane—more so, in fact, as the change may be more sudden.

Passenger Service. Where passenger carrying is concerned, the developments of the past year show conclusively that the aeroplane can be given more than sufficient capacity for all military purposes. Breguet has succeeded in carrying twelve passengers in a comparatively moderate-sized machine, a number which can undoubtedly be increased, so that with its greater speed the aeroplane can more than compete with the dirigible as a passenger carrier. It does not require a regiment of men to help it alight or get away, and a small building will house it. If necessary to stow it in a restricted space, this may be done by dismounting the wings, the reverse process of assembling being so simple that the machine can be made ready for service in an hour's time.

Behavior in a Wind. When the aeroplane first came into prominence several years ago, its then present and future possibilities were very much belittled. The general consensus of opinion at that time of those who pinned their faith to the dirigible was that the aeroplane was merely a scientific toy—an experiment of the laboratory being carried out on a larger scale and nothing more. There seemed but little question that the airship was the most practical means of navigating the air; any comparison was one-sided and all in favor of the dirigible, for up to that time aeroplane performances had been confined to very short flights, usually with the aviator alone, and then only in the calmest weather. In contrast with this, the dirigible could remain aloft and combat winds that were then considered dangerous to the aeroplane, so that despite the fact that the dirigible has never represented anything but a most precarious and costly method of navigating the air, it was the most practical means of doing so available up to about 1906. The comparatively few years that have intervened have totally changed its status. Flights such as those made by Johnstone and Hoxsey at the International Meet in the fall of 1910, during which they were driven backward 40 and 30 miles, respectively, by a wind exceeding 50 miles an hour, after which both alighted safely, demonstrate conclusively that the aeroplane is now vastly the superior of the dirigible as far as keeping to the air in stormy weather is concerned. Under the same conditions, the motors of the most powerful dirigible ever built would have been helpless; an attempt to land would have meant inevitable destruction of the airship and probably the death of some of its crew, and yet, as the ocean was right at hand in the case in question, there would have been no alternative but to land despite the gale that was blowing.

Portability. Where it is impractical for strategical reasons to fly from the point at which aeroplanes are permanently stationed, they may be partly dismantled by folding the wings, may be placed on a specially designed automobile as shown in the Bleriot war monoplane Fig. 2, and be transported a considerable distance in less time than is necessary to get an airship out of its shed, thus approaching an enemy's location from an unexpected direction. In the same manner, they can always be carried along as a regular part of an army's field equipment, and may be sent aloft at short notice. They may also be carried on naval vessels in the same capacity and undoubtedly this will be the case in the near future, as the result of the highly successful experiments made in this country. At a considerable height, well within the range of the aviator's vision, an aeroplane is not alone an extremely difficult thing to hit, but likewise a very difficult thing to see at all and can be followed only by close concentration on the part of the observer. The dirigible, on the other hand, is always plainly visible, even at heights that would render observations on the part of its crew of very little value. Unless struck in a vital part, disabling the motor or killing the aviator, a chance shell would not interfere with an aeroplane's flight, but a single rent in the envelope of a dirigible of the flexible type would terminate its voyage then and there, the Zeppelin multi-cellular type with its numerous independent gas bags being free from this disadvantage.

Fig. 2. Bleriot Military Monoplane, Showing Portability Feature

But despite its manifold shortcomings, the various Zeppelin disasters, the numerous serious mishaps that have befallen the

German military dirigible Parseval, and the several misfortunes of different French airships, governments will probably continue to build dirigibles. The French and German military departments, however, having had a wide experience in this field, are devoting a great deal more attention to the aeroplane, France having been the first to officially adopt this fourth arm as a part of its military service, and now having an aerial fleet far outnumbering that of any other nation. England, too, will probably question carefully further developments along this line in view of her recent experience with the huge British naval dirigible Mayfly, which, although completed late in 1911 at an enormous cost, was completely wrecked at the first attempt to take it out of the shed. Through what has generally been regarded as ultra-conservatism, the United States has not had to pay for the experience which European governments have paid so highly for—its one small dirigible is said to have cost but $30,000, or less than the expense of fitting up one of the large French or German airships—and there appears to be but scant prospect that any more money will be spent in this direction in America.

Recent Developments in Dirigibles. *Types.* Despite the destruction of the various Zeppelin airships, their builder has never lost faith in the rigid type of dirigible he has evolved, and interest in aerial passenger transportation in Germany is on the increase rather than otherwise. The Zeppelin VI made 34 trips, but bad weather was so constant that she was able to sail only on 19 days out of the total of 25 that the ship was in commission before being destroyed. On these trips, 406 passengers were carried, in addition to a crew consisting of a captain, two pilots, and five engineers, or an average of 20 persons per trip. The trips varied from 50 to 125 miles each, and some idea of the financial return may be gained from the fact that during the short time it was in operation, the ship brought in $19,000, of which $11,215 was profit. So promising is the financial reward accruing from the operation of aerial passenger lines that there are several in Germany, and if press reports appearing during the winter of 1911 have a basis of fact, a similar enterprise on a smaller scale should be established during 1912 between Philadelphia, New York, and Atlantic City, it being reported that airships of the Parseval type had been acquired for the purpose. The Zeppelin Airship Construction Company has been incorporated in Germany with $3,000,000 capital to carry forward Count Zeppelin's work, and an immense plant has been established at Friedrichshafen for the construction of the huge rigid dirigibles. One of the first that was built there was the Deutschland II, which went into commission in the fall of 1910; a great deal was expected of her during the following year when she was to be stationed at Düsseldorf, first for making excursion trips of 100 to 150 miles, and ultimately to carry on a regular passenger service between Düsseldorf and Hamburg, but she was wrecked after a comparatively short time in commission in much the same manner as most of her predecessors. The Schwaben was put into service shortly after and proved very successful, having made 140 trips during 1911, carrying a great number of passengers, her immunity from accident being due in large part to the improved methods of handling the ship in docking. The Deutschland II was 485 feet long by 46 feet in diameter, the Schwaben being slightly smaller. Duralumin, a new alloy of aluminum of greatly increased tensile strength, has been adopted for the frames, increasing the passenger capacity to 26, as compared with 20 in the older ships. The design has also been modified by allowing sufficient space between the outer covering of weatherproof cloth and the silk gas bags to permit of a constant draught of air over the latter, thus keeping the temperature approximately uniform and preventing sudden expansion or contraction of the hydrogen.

It will be apparent from this that Germany has commercialized the dirigible on a large scale—in fact, there is little or no conception here of the amount of money that is being expended on the airship abroad, as may be noted from the following resumé of some of the large dirigibles now in existence.*

The huge French airship Clement-Bayard II and the English Morning Post were largely the result of popular rivalry between the two nations in this field. The latter has a capacity of 353,000 cubic feet and, with the exception of the rigid Zeppelins, was the largest airship ever constructed, up to the time of its building. It has since been surpassed by the German non-rigid Krell I, a giant of 459,160 cubic feet capacity. The experiences of military service have evi-

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*"In existence" must be regarded as referring only to the time at which it was written. It only takes a few minutes to demolish a dirigible, but months or a year may be necessary to rebuild it.—Ed.

dently shown the necessity of greatly increasing the size of the vessels, but not to the extent that obtains with the passenger-carrying craft. Thus the new French Captaine Marechal, named after the Republique's unfortunate commander, displaces 254,304 cubic feet, or nearly three times that of La Republique, while the new Italian military dirigible has a displacement of 282,560 cubic feet.

As a general rule, the French have devoted more attention to the construction of airships than to the art of handling them, so that during last year's military maneuvers, some of their dirigibles had narrow escapes. With the exception of the small Zodiacs, the French military airships are rarely used to the extent that one would expect. In England, airships have been developed by the army on a small scale. As a sea power, England is naturally concerned with the development of the dirigible as an auxiliary to the navy. Big though they were at the very outset, the Zeppelins have grown from 59,160 to 706,400 cubic feet capacity. The British naval dirigible begins at the latter figure. The latest passenger airship built for Belgium by the French Astra Company, the Ville de Bruxelles, displaces about 282,560 cubic feet. On the other hand, the most advanced experimental types, the German Krell I and the British Mayfly, were designed solely for military purposes. The new Belgian ship, however, is an interesting type. The single large propeller of the classic La France of 30 years ago is still retained, in addition to which there are the two elevated side propellers, driven by a separate motor, as in the Clement-Bayard design, but somewhat smaller in size. The result is that the ship remains under control even after the front propeller is stopped in landing. The Parseval form of envelope, characterized by the blunt, ovoid bow, is employed. It is hardly necessary to discuss the comparative merits of the so-called flexible, semi-rigid, and rigid systems of construction in this connection. The very largest sizes must, of necessity, be rigid. For the smaller airships, each system has its own advantages and disadvantages. England and France now have rigid types, as well as Germany. France is the home of the dirigible, but the French, who were responsible for its invention, have not developed lighter-than-air craft as systematically as the Germans.

Refinement of Details. The tremendously increased size of the up-to-date airship has tended to greater refinement of detail. Donkey engines are becoming a common feature of their motor equipment, the Krell I, the Akron, Vaniman's transatlantic dirigible, and Brucker's transatlantic trade-wind ship, the Suchard, all being fitted with them. The gas bags of both rigid and non-rigid dirigibles are subdivided into compartments like a ship, this construction having been first introduced in the Zeppelins. Multiple balloonets are also being adopted in greater number, the good features of one ship being promptly copied in another. Thus, the English Zeppelin "Mayfly" adopted the propeller mounting of the Krell I, the object being to avoid long transmissions. In shape, it also approached the non-cylindrical form, the Zeppelin, however, still remaining essentially cylindrical. The larger the ship, the more elaborate is its equipment. Wireless telegraph apparatus is now carried by the Zeppelin passenger ships as well as by the military dirigibles, so that the navigator may constantly keep in touch with meteorological stations and be kept informed as to the weather. Valuable experiments have been carried out by the Zeppelin company to guard its airships against atmospheric electricity. In fact, the Zeppelin company profits by its experience and tries to prevent the same accident being repeated. Thus, the new Deutschland had an increased dynamic lift, an improvement that was made immediately following the disaster to its predecessor. As a result, this dirigible rose to a height of 3,800 feet without casting over any ballast; this lift later proved insufficient and the Schwaben was further improved. Probably the Zeppelin type would be still better if it had a continuous car like the Akron, containing the motors and crew, in place of two cars which are really a legacy of the old spherical balloon. Adherence to type has hampered the development of the airship, just as it kept back the improvement of the railway car. Just as early railroad coaches were merely enlarged horse-drawn coaches, so the modern dirigible, in a sense, is still an enlarged, elongated, spherical balloon, equipped with a motor. Obviously, an airship should have the same unbroken lines below as above to insure speed, and this idea has been carried out by Vaniman in the Akron.

Air Pilots. To guide one of these huge craft through atmospheric disturbances of more or less violence requires considerable skill, and the long period of apprenticeship necessary in the construction and piloting of a dirigible—a period which is longer, strange as it may seem, than in the case of the aeroplane—accounts for the slow development of the types with which we are familiar. Although the German army experiments daily in the air, the tactical handling of dirigibles is still shrouded in mystery. No doubt, there are definite rules to be followed, but what they may be can only be surmised. Even night trips are said to be frequent with the German military dirigibles.

Major von Parseval has said of the competent air captain: "He must know exactly the speed of his ship and of its maneuvering ability. Above all, he must have a nice sense of the responsiveness to the vertical steering apparatus, and be able to estimate the ship's carrying capacity with considerable accuracy."

On trips from Munich, the L. P. VI covered 3,000 miles and, with frequent small injections of fresh hydrogen, has remained inflated for twelve weeks. On one trip she combated a gale of 34 miles an hour, a speed hardly exceeded by the vessel at its best. The captain made considerable headway by tacking into lulls, keeping the harbor well to leeward, ready to return and land at a moment's notice. This was airmanship of a high order. This ship has had the unique experience—for air craft—of being chartered for a special trip to Kiel, which it is proposed to make as important an airship station as it now is a naval base. And the ship has also added to its revenues as a passenger carrier by serving as a background at night upon which to throw stereopticon advertising.

Air Harbors. With the aeroplane, the question of housing is a simple matter, Fig. 3, but as each new military airship has become larger, the problem of sheltering it has become more difficult. Fig. 4 gives some idea of the size of the harbor for a modern dirigible. It has resolved itself into a question of establishing a number of permanent harbors in Germany. These are on a truly colossal scale, those at Königsberg and Thorn, fortresses on the German frontier, have been designed to house ships half as large again as the biggest vessels now in service. For craft so huge, portable sheds are out of the question. Permanent harbors must be constructed, which will serve as bases for craft having a wide radius of action. The new Zeppelin air harbors are on an elaborate scale. To the stations already established at Düsseldorf and Baden-Baden, a number of others are now being added, and smaller cities that can not afford to provide great harbors with sheds are establishing landing places with moorings, and aerial beacons will shortly become common, judging from the success of those in use at Spandau and Munich. Dirigibles are started on their journeys and docked by large

Fig. 3. An Aeroplane Hangar

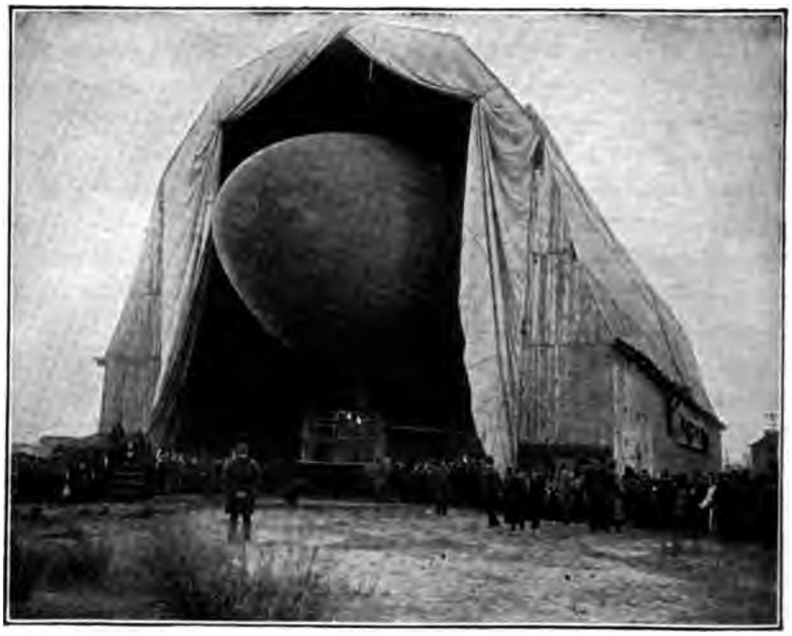

Fig. 4. Immense Harbor Necessary for Vaniman's Transatlantic Dirigible "Akron"

forces of trained men, but even long practice has not enabled them to handle such huge air craft as the Krell I and the Schwaben, with ease. The docking of a big dirigible is a ticklish operation at best and is made dangerous by a cross-wind, only the new system of anchoring devised for the Schwaben having prevented damage to that ship. To cut down the expense necessarily entailed in maintaining such a large force, the Krell I is docked partly with the aid of electric winches, and this is something that will probably undergo considerable development.

Just now, inventive ingenuity is concentrated on the airship itself, but the time will soon be ripe for a consideration of the problem of handling the ship by machinery entirely. Of these problems, probably the most difficult is that of anchoring an airship in a high wind—in the Krell I, it is solved by employing a multiple anchor cable which is led to the nose of the ship and there divided. The 24 single ropes into which it separates are fastened all round the envelope, where the diameter is not less than 20 feet.

Improvements of Design. Where the construction itself is concerned, all other difficulties of building large airships are summed up in the well-known fact that, as a structure increases in size, the margin of safety does not increase in proportion. In other words, to build a successful airship 300 feet long on exactly the same lines as one 150 feet long, it would not be correct, from an engineering viewpoint, to scale up the parts of the smaller craft to the proportionate size of the larger. The big Morning Post, which is a Lebaudy of 353,200 cubic feet displacement, is simply a Lebaudy of 105,960 cubic feet, enlarged line for line. There is but a single car, very close to the envelope at that. But it can not be denied that the crossing of the English Channel at its widest part and its journey from Moissons to Aldershot in five hours and in a strong wind, shows that size must be very greatly increased before the structural danger point is reached. The Krell I seems to embody the opposite principle, namely, that an increase of size beyond 105,000 cubic feet involves the very best efforts of the engineer to increase the factor of safety proportionately. There are not simply two cars instead of one, but three, so suspended that the pull on the gas bag is all in a vertical direction, differing radically from the oblique suspension and pull in the Morning Post. Hence, in the Krell I a minimum strain is imposed upon the envelope. It is true that the latter ship is uncommonly slender in spite of the absence of the stiffening frame on which the Morning Post essentially relies. Whatever may be the shape of envelope, the material is subjected to tensile stresses only.

The new German military dirigible M. IV is provided with a very substantial stiffening frame, so designed that the load is divided in half. Its engine power has also been very substantially increased. Zeppelin's Deutschland II was considerably lightened without any fundamental change in plan or material, the girders being redesigned more effectively. The British dirigible Mayfly, of very similar type, was built of duralumin, the result being that its engine power was higher, and that its radius of action for the same displacement should have been greater. Both the Deutschland and the Mayfly were nearly identical in design with the first Zeppelins of 459,000 cubic feet only. In neither case was it considered necessary to increase the margin of structural safety with the size, and both were wrecked after a short period, the British ship before it had seen any service.

The foregoing will suffice to give some idea of the exceptional activity that characterizes the present development of the dirigible abroad, as compared with the utter apathy with which it is viewed in this country. Americans who have not gone abroad have never had an opportunity of seeing a modern dirigible as exemplified by the German and British types referred to above, but if the American service mentioned should prove successful, those in the East may see similar dirigible airships in passenger service.

REWARDS OF AVIATION

Human nature is so constituted that men may be found to attempt anything if the financial reward be sufficiently large; and it is this spirit that makes the impossible of today the achievement of a week or so hence, as is strikingly illustrated by the rapidity with which records were surpassed during the past two years. In reviewing the latter, due credit must be accorded the powerful incentive to extraordinary effort represented by the cash prizes offered both in this country and abroad. Despite the large sums given, the breaking of a record has immediately brought forth offers of still larger amounts. The achievements of the past few years have been paid for at a cost exceeding a million dollars in prize money alone, and it goes without saying that this has spurred aviators on to efforts that probably would not have been made otherwise until some time later. The following are some of the prizes won during 1910 and 1911, as well as a number still standing or to be offered during 1912.

Prizes for Flights. The International Trophy, Fig. 5, was offered by James Gordon Bennet and was first competed for in connection with the International Aviation Meet, at Rheims, France, where it was won by Glenn H. Curtiss in a Curtiss biplane in August, 1909. In the following year it was competed for at the International Meet held at Belmont Park, New York, in October, 1910. In this event Leblanc broke all records for distances up to 95 kilometers, but when he had the victory in sight with several minutes lead, the gasoline supply failed and his machine dropped on a telephone pole. The machine was a 100-horse-power Bleriot, and was completely wrecked, although Leblanc escaped without injury. This allowed Claude Grahame White to win in a 50-horse-power machine of the same type.

The prize is offered for the fastest time over a three kilometer circular course and is to be competed for in the country of the previous winner. The trophy is to be awarded permanently after having been won three times consecutively by an aviator of the same nationality. As Grahame-White is an Englishman, the third competition was accordingly held in Great Britain in July, 1911, the trophy being won by an American for the second time. This was Weyman, who drove a Nieuport monoplane equipped with a 100-horse-power Gnome motor. The distance was originally 100 kilometers, but as the staying capacity of the aeroplane developed so rapidly, this was held to for only two years, the distance in 1911 being 150 kilometers.

The first substantial prize to be won in this country was that of $10,000 awarded by the *New York World* to Glenn H. Curtiss for his flight, on May 29, 1910, from Albany to New York, a distance of 148 miles. This immediately led to the offer of $25,000 by the *New York Times* and *Chicago Evening Post* to the winner of a race between the two cities, the only conditions being that there must

Fig. 5. Gordon-Bennett International Trophy

be at least three competitors and that the total time for the trip must not exceed 168 hours. This amount was increased by the offer of the Pennsylvania Aero Club of $1,000 for a week's exhibition of the winning machine, with a further increase of $1,000 offered by Clifford B. Harmon to the first aviator to keep the air for 500 miles consecutively in that race, bringing the total winning possible in this event to $27,000. This was exceeded by the offer of $30,000 by the *New York World* and the *St. Louis Post-Dispatch* for a flight between St. Louis and New York, and the $50,000 prize put up by William R. Hearst for the first successful flight from the Altantic to the Pacific in a dirigible, the latter having the great disadvantage that the cost of a machine capable of making the trip would exceed by several times the amount of the reward, whereas the cost of an aeroplane is but a fraction of some of the larger prizes. It was later extended to cover an aeroplane flight as well.

Two attempts were made to win the Hearst $50,000 prize during the fall of 1911, but neither succeeded in complying with the conditions, which called for the crossing of the continent in 30 days. C. P. Rodgers in a Model "B" Wright machine made the journey from New York to Pasadena by way of Chicago, Kansas City, Dallas, and San Antonio in 59 days, the distance being 3,390 miles. Although the airline distance is only 2,540 miles, it will be some time before an aviator will feel sure enough of himself to follow an airline route. Rodgers was greatly delayed by numerous mishaps and also by stopping for exhibition purposes. He was convoyed by a special railroad train, one car of which was fitted as a machine shop. On attempting after a rest at Pasadena to make the remaining 25 miles to the coast at Long Beach, his aeroplane fell and the plucky aviator nearly lost his life. Notwithstanding his machine was almost a total wreck, it was again repaired and Rodgers finished his journey about a month later, thus completing what must be considered a very noteworthy flight.* Fowler, who started from the west coast, was even more unfortunate and had to give up the attempt to cross the mountains after several trials, taking the southerly route instead. His ill-luck still pursued him, so that after more than three months' work he had

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*After completing his coast-to-coast journey, Rodgers had been making almost daily exhibition flights over the water at Long Beach, California. On April 3, 1912, he misjudged his proximity to the surf at the end of a "volplane" from a height of 200 feet, dashed into the water, and was almost instantly killed.

succeeded in getting no farther than New Orleans. He subsequently completed the trip, landing at Jacksonville, Florida.

That these prizes, on the one hand, are not unusually large, nor, on the other, merely prizes that may be won in the indefinite future, is amply evidenced by some of the winnings of foreign aviators in the past. The most prominent of the latter was naturally the $50,000 prize won by Paulhan in his flight from Manchester to London, April 28, 1910, while Wynmalen, the Belgian aviator, won

Fig. 6. Michelin Trophy for Longest Continuous Flight

$20,000 on October 16, 1910, by his flight from Paris to Brussels and return in less than 36 hours. The Michelin prize of $20,000 together with the Michelin trophy, Fig. 6, were gained by Tabuteau for his flight of 365 miles, Fig. 7, the longest continuous flight made during 1910 but which was surpassed by a substantial margin in 1911. Fig. 8 shows the enormous gasoline tank necessary for this performance, while Fig. 9 shows the provisions for protecting the operator. It was in attempting to win the Michelin prize that Moissant lost his life at New Orleans, on December 31, 1910. Another Michelin prize of $20,000 is for a flight from Paris to the Puy de Dome with a passenger. This is a mountain 4,800 feet high and about 217 miles in an airline from the French capital, the conditions being that the aviator must circle the cathedral spire at Clermont-Ferrand on the way, and that the trip must not consume more than six hours. Several attempts to win this prize have been made without success. Weyman flew within 13 miles of the goal on September 7, but lost his bearings and was compelled to descend owing to fog and rain. Morane, who was to have competed at the International Meet near New York, made an attempt on October 22, but was seriously injured through the fall of his 100-horse-power Bleriot soon after leaving Paris. It was finally won in an M. Farman biplane in the summer

Fig. 7. Tabuteau, Winner of Michelin Prize in 1910, in Flight

of 1911. Still another prize and the British Michelin trophy, Fig. 10, were won by Cody in his biplane, when he covered 194.56 miles in 4 hours and 50 minutes.

Prizes of similar amounts are not lacking in this country; among them may be mentioned one of $20,000 offered by the Aero Club of Washington to the Wright Brothers for a flight from New York to Washington, if they will enter one of their machines against a Curtiss, while a prize of $10,000 is offered by James H. Moore, of Rochester, New York, for a flight from that city to Detroit, Michigan. The conditions in this case are to be left to the decision of a committee of aviators. More than one attempt has already been made to win this by local talent, but with scant success. Numerous prizes

Fig. 8. Close View of Tabuteau Showing Immense Gasoline Supply Tank

have also been offered and won for altitude flights, Brookins placing $5,000 to his credit by his record-breaking ascent at Atlantic City on July 9, 1910.

Naturally, the largest aggregate amounts are those offered at prominent meets, the winnings of the aviators at the International

Fig. 9. View of Operator's Seat in Aeroplane Designed for Altitude Flights, Showing Means of Protection from Extreme Cold

Meet at Belmont Park in October, 1910, having reached a total of approximately $200,000, the participants in this case also having been awarded a share of the gate receipts. Before the opening of the meet, $50,000 was appropriated for cash prizes, as follows: three prizes of $4,500 each for speed, altitude, and distance; an altitude record prize of $5,000 or $10,000 for the aviator first to reach

10,000 feet; in addition there were what might be termed consolation prizes amounting to $250 for each hour the aviators were in the air during the duration, speed, and altitude tests. (See Fig. 11.) These were supplemented by correspondingly large amounts

Fig. 10. Michelin British Trophy for Distance Flight

for cross-country flights, as well as prizes for passenger carrying, relay messenger service, slow flying, quick starting, and other feats, besides which there was a prize of $10,000 for the winner of a race from Belmont Park round the Statue of Liberty and back.

At smaller meets, the amounts offered have been proportionately

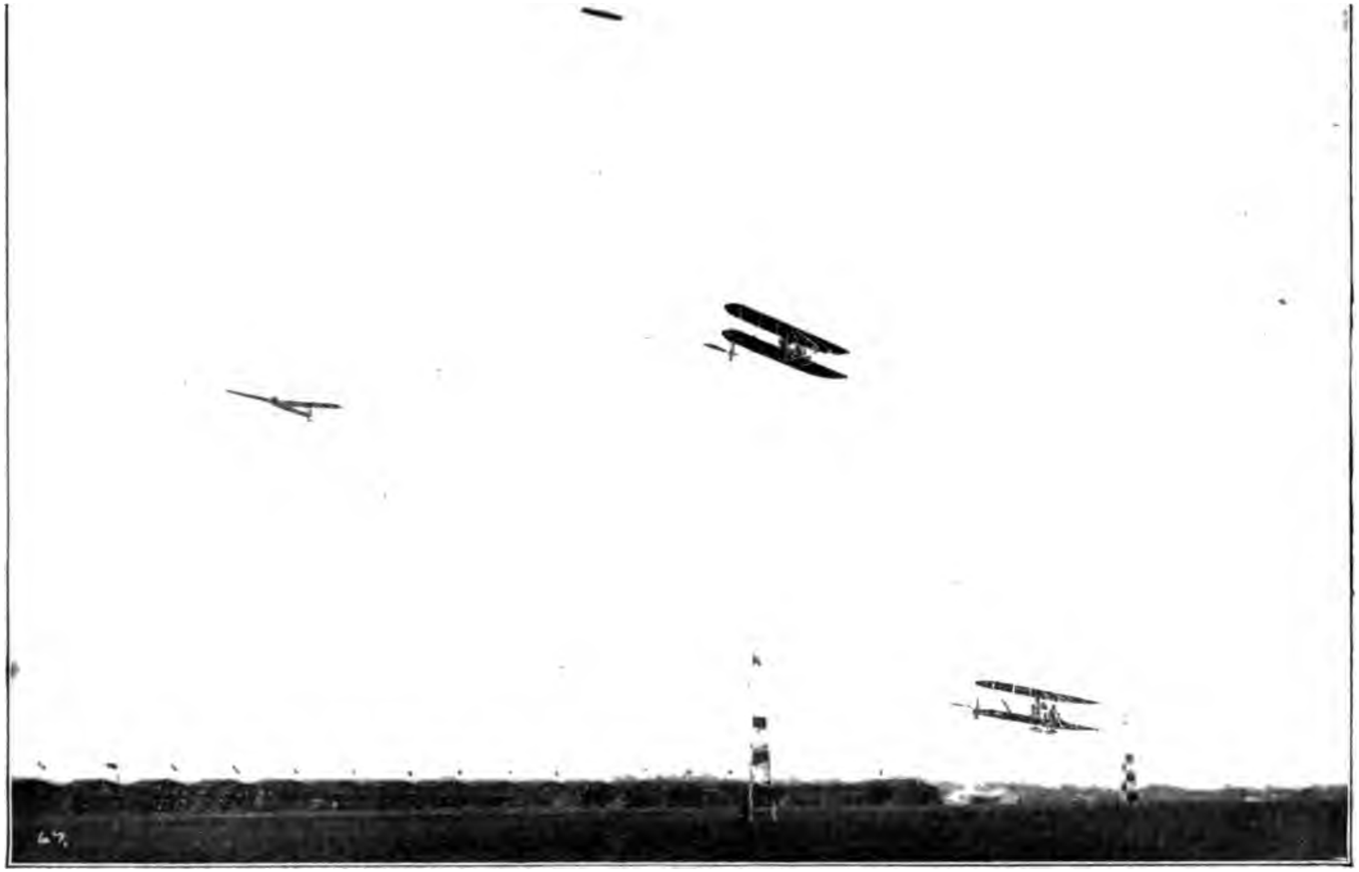

Fig 11. Typical Scene at an Aviation Meet

large, the *Boston Globe* offering $10,000 for the fastest trip over the water from the aviation field at Atlantic City round the Boston Light and back on the occasion of the Harvard Meet near Boston, in September, 1910. In addition to this, first, second, and third prizes of $3,000, $2,000, and $1,000 were offered in the speed and altitude events, and $2,000 and $1,000 in the duration and distance competition, the making of a world's record, in either case, adding $1,000 to the amount. Other prizes were $1,000 and $500 for the slowest lap of the course, with smaller amounts for the quickest start, accuracy, and the like, the total offered aggregating $41,000. At the Baltimore Meet, in November, 1910, there was one prize of $10,000, two of $5,000 each, three of $3,500 each, one of $1,500, and so on down, totalling $32,700.

The Los Angeles Meet, in January, 1911, was the first to include prizes for dirigibles. In addition to one of $10,000, one of $7,500, and four of $5,000 each, for aeroplanes, a prize of $10,000 was offered for a flight by dirigible from Los Angeles to San Francisco, and another of $5,000 for a non-stop flight by a dirigible carrying more than two passengers from Los Angeles to San Diego and back. The distances are 450 and 150 miles, respectively. A $10,000 prize was also offered for a trip to the Atlantic Coast without landing, and $5,000 for the first balloon to land east of the Mississippi without having come to earth en route, with a further balloon prize of $2,500 for breaking Count de la Vaulx's record of 1,193 miles and $2,500 more for the first balloon to land within five miles of San Francisco. That the coast-to-coast balloon trip is not quite as chimerical as may appear at first sight from the mere offer of a prize, is evident from the fact that P. C. Thompson has offered $10,000 to Charles J. Glidden, the well-known balloonist, to finance a trip of this kind, and the offer has been accepted. A trophy worth $1,000 is offered for its successful completion, and no conditions are imposed other than that the start shall be made at some point on the Pacific and that the balloon shall land not less than 50 miles from the Atlantic Coast. H. H. Clayton, who acted as aid in the Pommern which won the International Balloon Race in 1908, will probably be the pilot.

As the intention is merely to chronicle the extremely strong incentive that is being offered in the form of substantial financial reward for record-breaking performances, no attempt has been made to detail a complete list of the prizes either won or offered, there being many of the latter in addition to those already mentioned, such as the prize of $5,000, for an aeroplane flight over the 90 miles of the Caribbean Sea separating Key West from Havana. This was awarded to McCurdy, one of the Curtiss aviators, although his motor broke down when he was within a few miles of Havana, having flown 87 miles.

Prizes for Improvements. No mention of the reward phase of aviation that has done so much to foster interest and bring about such startling achievements would be complete without at least a reference to prizes offered for improvements in construction, as the latter are, in reality, of more importance than achievements which merely illustrate what the present machines are capable of in the hands of skilled and daring aviators. The largest of these was granted to Edouard Nieuport as the winner of the French military competition for army aeroplanes; the bonus and value of the order for machines placed reached a total of $156,900; the second, Breguet, received $83,000; and the third, Deperdussin, $59,000.

In America, Edwin Gould has offered a prize of $15,000 for "the most perfect and practicable heavier-than-air flying machine, designed and demonstrated in this country, and equipped with two or more complete power plants (separate motors and propellers) so connected that any power plant may be operated independently, or that they may be used together." During the two years that this prize has been open, only one or two attempts have been made to win it. One of these was the Queen biplane, built near New York, which came to grief at the Nassau Meet, in September, 1911, after a short flight. The Short biplane, described under "Special Types," appears to be the first successful machine of the kind, though Sommer made a series of short flights on a machine fitted with two motors in the latter part of 1910. As both of these are foreign machines, however, they would not be eligible.

Cost of Equipment and Maintenance. While the rewards offered are unusually large and the winnings of some aviators have amounted to a small fortune in the course of little more than a year, the expenditures for machines and repairs are on a proportionately elevated scale. Following are some of the prices of the foreign machines exhibited at the Olympia show in London, in the latter part of 1910.

Wright biplane with Wright motor (English manufacture) $5,839; Farman biplane with Green motor $4,428; and with Gnome revolving motor $5,450; Voisin biplane with E. N. V. motor $3,796; Antoinette monoplane with Antoinette eight-cylinder, V-motor $4,866; Bleriot "Cross-Channel" monoplane $2,336; Santos-Dumont monoplane $1,460. In this country, the Wright machines list at $5,000 for the standard type and $7,500 for the racer with an eight-cylinder, 60-horse-power motor, and a glance over the prices of the machines exhibited at the Boston and New York shows during 1910 make it apparent that an investment of at least $4,000 to $5,000 is required in the purchase of a machine of any reputation. An American-made Voisin shown at Boston, listed $3,450; while an American Blerioplane was $3,750, which included instruction in its operation. As is the case with automobiles, however, machines may be had all the way from $1,000 up, with no limit on the latter.

In addition to the expense for machines, of which every prominent aviator owns several representing an investment of $25,000 or more, there is the cost of maintenance, viz, transportation charges for machines, and expenses for mechanics, fuel, oil, and repairs. Of these charges, the last is by far the most serious; transportation charges are high, as are also the expenses and wages of the mechanics; fuel and oil do not cut much of a figure, but the cost of repairs may exceed them all. Just a slight swerve in alighting, a gust of wind gets under the upraised wing tip and the other strikes the ground; the complete wing structure on that side is demolished—damage $250. Or again a propeller strikes an obstruction when the motor is started and cracks a blade—that means replacement at a cost of $50 to $85. Slight damage to the motor which puts it out of commission for a day or two may occasion the purchase of another to take its place—expense, anything from $500 up to $2,000; so that expenditures as well as winnings run up into many ciphers.

AVIATION RECORDS

Regardless of how great the achievements of the future may be, the record of man's flights in heavier-than-air machines during the first few years of his conquest will go down into history as representing an advance wholly unparalleled in any other field of endeavor in the same period. To have progressed from a flight lasting twelve seconds, during which the machine was not really under control, to flights limited in distance or altitude only by the endurance of the aviator or the amount of fuel carried, in little more than seven years, is certainly a record of performance unapproached.

Early Records. On the occasion of their first and second trials with the power-driven machine at Kitty Hawk, North Carolina, on December 17, 1903, the Wright Brothers made a flight of 12 seconds in a 27-mile wind. On the fourth trial, a flight lasting for 59 seconds and covering a distance of 852 feet was made the same day in a 20-mile wind and was the first actual flight by man in an aeroplane, demonstrating that the aviator had control of the machine. In August, 1904, at Dayton, Ohio, a flight of 1 minute duration was made, while on November 9, of the same year, a flight of 3 miles, lasting for 5 minutes 4 seconds, was made with the second power-driven machine ever built. During 1904, the Wright Brothers made 105 flights in all. In 1905 they made 49 flights, the performance of October 5, 1905, being longer than all of those preceding it put together. The time of this flight was 38 minutes 3 seconds, covering 24⅕ miles, which was the world's record for some time thereafter. This flight followed one of 11⅛ miles in 18 minutes 9 seconds, on September 26, 1905. No flights were made during 1906 and 1907.

A number of short practice flights were made at Kitty Hawk, North Carolina, in the spring of 1908, and on October 18, 1908, at Le Mans, France, a flight of 1 hour 54 minutes 53⅗ seconds was made, covering a distance of 62 miles, and on December 31, 1908, 77 miles were covered in a single flight in 2 hours 20 minutes 23⅕ seconds. No less than 100 flights were made at Le Mans, France, during which 36 people were taken up as passengers. All of these flights were made by Wilbur Wright, who was accordingly the first man to remain in the air for 2 hours.

Orville Wright made the first flight in a power-driven machine at Kitty Hawk, North Carolina, a mere glide of 12 seconds, and not to be compared for length or duration with glides previously made in planes without motors. As already noted, Wilbur Wright's first attempt was no better. On September 15, 1904, at Dayton, Orville Wright made the first turn in an aeroplane and five days later accomplished the first complete circular flight ever made. On September 9, 1908, at Fort Myer, Virginia, he flew at an altitude of

TABLE I

Aeroplane Records for 1909 and 1910

Aviator	Aeroplane	Date	Distance miles	Time H. M. S.	Remarks
Latham	Antoinette monoplane	July 19, '09	11		Fell into the English Channel.
Bleriot	Bleriot monoplane	July 25, '09	25	0 37 00	First cross-channel flight. Sangatte to Dover.
W. Wright	Wright biplane	Oct. 4, '09	21	0 33 33	Over Hudson River.
Paulhan	H. Farman biplane	April 18, '10	108	2 3 00	Chevilly to Chalons in two stages. Record for distance and duration to date.
White	H. Farman biplane	April 23, '10	117.2	2 50 00	London to Hodmore, one stop at Rugby, in London-Manchester race.
Paulhan	H. Farman biplane	April 23, '10	193	4 12 00	London-Manchester, 1st stage 117 ms. Average speed 44.34 ms. per hr.
Rolls	Wright biplane	June 2, '10	50	1 30 00	First round trip channel flight.
Curtiss	Curtiss biplane	May 29, '10	142.5	2 50 00	From Albany to Governor's Island in New York harbor. Flight made in three stages, time being total in air.
Hamilton	Curtiss biplane	June 13, '10	149.54	3 27 00	Governor's Island, N. Y., to Phila. and return—two stops, one accidental.
Curtiss	Curtiss biplane	July 11, '10	50	1 14 50	World's record for continuous flight over water. Carried pontoons and air bags. Made at Atlantic City.
Olieslagers	Bleriot monoplane	July 7, '10	158.45	3 39 29	Longest single flight to date. At Rheims, France.
Labouchere	Antoinette monoplane	July 9, '10	211.27	4 37 00	First to fly continuously for 200 miles.
Olieslagers	Bleriot monoplane	July 10, '10	244.04	5 3 05	First to fly for five hours continuously.
Moisant	Bleriot monoplane	Aug. 7, '10	25	0 32 00	First crossing of English Channel with passenger.
Le Blanc	Bleriot monoplane	Aug. 7, '10	485		Flew over circular course around France. Race from Paris and return, one stage per day regardless of weather. Time 10 ds. 12 hrs. 15 m. Longest stage 75 ms.
Aubrun	Bleriot monoplane	Aug. 7, '10	485		Finished 20 m. after Le Blanc over same course.
Curtiss	Curtiss biplane	Aug. 31, '10	64.75	1 42 00	From Cleveland, O. to Cedar Point, O., over Lake Erie. Carried pontoons and air bags.
Cattaneo	Bleriot monoplane	Aug. 13, '10	141.1	3 18 9	British record.
Johnstone	Wright biplane	Sept. 3, '10	101	3 5 40	American record made at Atlantic, Mass.
Brookins	Wright biplane	Sept. 29, '10	192.5	5 49 00	Chicago to Springfield, Ill., in two stages, first one of 88 ms.
Hoxsey	Wright biplane	Oct. 8, '10	109	3 33 00	Springfield, Ill. to St. Louis, in two stages, first one of 104 ms. American record.
Tabuteau	M. Farman biplane	Oct. 28, '10	289.3	6 1 35	First man to fly for 6 hours continuously. World's record.
Ely	Curtiss biplane	Nov. 14, '10	4	0 5 00	Flew from deck U. S. S. Birmingham to Virginia shore opposite Fortress Monroe.
Tabuteau	M. Farman biplane	Dec. 31, '10	365	7 0 00	Winning Michelin prize of $20,000. 42 other aviators competed. First won by W. Wright in '08—78 ms. in 2 hrs. 20 m.
H. Dutrieu	H. Farman biplane	Dec. 20, '10	105	2 33	Winner of "Femina" cup and prize—longest flight by a woman.

150 feet, making a world's record, while three days later he flew for 1 hour 14 minutes 24 seconds, covering 50 miles at an altitude of 250 feet, again establishing a record for altitude.

Records for 1909 and 1910. By the beginning of 1910, 2-hour flights had become so common and so many were made during that year that it would take a volume to record them; the most notable, however, are given in Table I.

Records for 1911. Flights became so numerous during 1911 that it would be out of the question to attempt to give more than passing mention to some of the most prominent. The number of licensed pilots in America increased from 26 in 1910 to 81 in 1911, while it is conservatively estimated that there are not less than 2,000 flyers in France, and that, during 1911, they made 15,000 flights, none of less than half an hour, covering a total of 350,000 miles.

Every world's record which 1910 had placed so far in advance of anything previously accomplished was left far behind. Garros mounted 13,947 feet; Beachey volplaned more than 12,000 feet; Fourney flew for 11 hours without stopping; Gobe exceeded the distance record by 12 miles in three hours less time, and without a stop; Helen, two weeks after becoming a pilot, flew 750 miles in 14 hours, including six stops for fuel—in fact, only four days after receiving his certificate he flew 665 miles in 12 hours and 40 minutes with three stops; Nieuport and Vedrines made a speed of 93 miles an hour; Prier flew from Paris to London, 223 miles, without a stop; Rodgers flew across the American continent by easy stages, a distance of 2,567 miles, from New York to San Francisco, while Fowler made half the distance in the opposite direction; and Atwood flew from St. Louis to New York, 1,155 miles, and immediately afterward made the flight from Boston to Washington, 460 miles. Between May 1 and October 1, Renaux was credited with 6,830 kilometers (4,098 miles), made in trips of 100 kilometers each, while Beaumont covered nearly 3,000 miles in the three great European races. There were five of these events in all: Paris-Madrid, 726 miles; Paris-Rome, 910 miles; the 1,073-mile European circuit; the 1,093 German route; and the Tour of England, 1,010 miles. Fowler completed his transcontinental trip by the end of February, 1912, landing in Jacksonville, Florida.

In addition to the most striking performances already mentioned, numerous notable flights were made in America on American-built machines. Though it took 12 days in all, Atwood's flight from St. Louis to New York occupied only 28 hours 53 minutes actual flying time, during which the only attention required by the engine was the re-babbiting of two bearings. Lieutenants Ellyson and Towers of the United States Navy Aeronautical Corps made a non-stop flight of 138 miles over Chesapeake Bay at 56 miles an hour in the Curtiss navy hydroaeroplane, having just previously made a non-stop flight of 75 miles. Hugh Robinson made the hydroaeroplane record of the year by his flight of 314 miles down the Mississippi in three days, carrying mail. McCurdy flew from Key West, 89 miles, over the Caribbean and would have landed in Havana a few minutes later, but for the breaking of the crank case of his motor. Parmalee and Lieutenant Foulois flew 106 miles with army despatches from Laredo to Eagle Pass in 2 hours 10 minutes, returning over the same rough country with but one stop. Beachey and Robinson raced from New York to Philadelphia, 83 miles, and Atwood flew from Lynn to Providence over the water in 2 hours 45 minutes. M. B. Sellers flew with a motor developing a scant 6 horse-power, thus carrying the exceptional weight of 41 pounds per horse-power.

The seventeen aeroplane builders in France turned out over 1,300 machines in 1911, the motors fitted to them having an aggregate horse-power in excess of 60,000. Of this total, 813 of the aeroplanes were produced by only five of the leading French makers. The American production is estimated at 750 machines, but of these more than two-thirds were built in back yards, less than 200 having been turned out by the Wright, Curtiss, Burgess, and a dozen or more smaller concerns. The actual total was 174, of which 58 were for private use, 105 for exhibition purposes, and 11 sold to various governments. Out of the total produced by the five leading French builders, 410 were sold to various governments, 367 were used in exhibitions and in school work, and 46 for sporting purposes.

No new records were made in America in balloons or dirigibles during 1911, though two big races, the National and the Gordon-Bennett, were held from Kansas City. Germany and France lead in the construction of big airships, Germany having 26, either belonging to the government or available as a military reserve, while

France has 15. England, Russia, Austria, Italy, Spain, Belgium, and Holland have 25 more. The French airship "Adjutant Reau" holds the record for distance, duration, and altitude, making a continuous trip of 550 miles in 21 hours 20 minutes, during which an altitude of close to 7,000 feet was reached. The German passenger-carrying ship Schwaben made 140 trips, covering 12,670 miles.

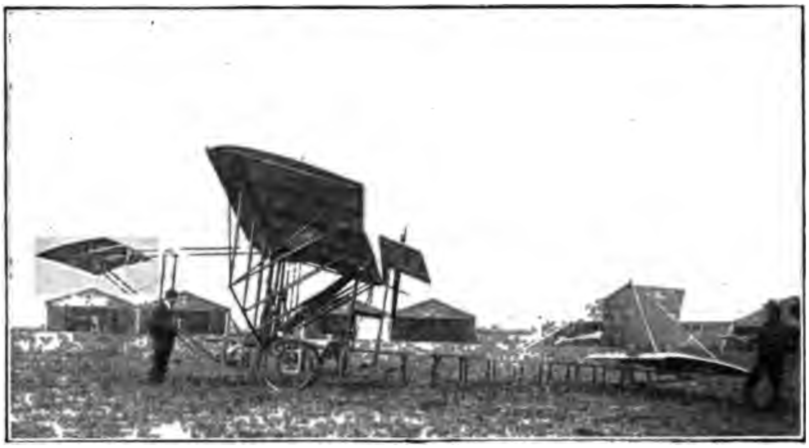

Fig. 12 Side View of Bleriot "Bus"

Fig. 13. Front View of Bleriot "Bus"

Passenger Records. Up to 1908, all flights had been made in machines carrying the aviator alone. The first flights with passenger, lasting more than a few seconds, were those of Wilbur Wright at Fort Myer, Virginia, in September, 1908, when he carried aloft first, Lieutenant Lahm for 6 minutes 26 seconds, then Major Squier, U. S. A., for 9 minutes 6 seconds. Later in the same month, at Berlin, he carried a German army officer aloft for 1 hour 35 minutes 47 seconds.

March 5, 1910, Henri Farman succeeded in carrying two passengers in the air, or three persons all told, for 1 hour 2 minutes 25 seconds. On April 20, Roger Sommer, in a Sommer biplane, carried four people—one a woman—for five minutes, while on August 29, Louis Breguet took up six persons all told, the total weight sustained being 923 pounds. In the fall of 1910, Bleriot built a machine to carry regularly eight passengers, *i. e.*, nine persons all told. Figs. 12 and 13 show side and rear views, while Fig. 14 shows details of the car. This machine, which was dubbed the "Bleriot Bus," was very successfully tried out in the early spring of 1911, making a number of flights which showed its ability to make a good speed despite the great amount of weight carried. This was in February, 1911, and scarcely a month had passed before Louis Breguet made an astounding flight of 3 miles with 11 passengers besides the aviator, or 12 people in all,

Fig. 14. Close View of Bleriot "Bus," Showing Seats for Passengers

at a speed of 55.9 miles an hour. The weight of the machine complete was 1,322.75 pounds, and the live load transported was the same, making the total load taken aloft 2,645.5 pounds, or more than 1¼ tons, this being the first flight on record in which the weight of the load has been equal to that of the machine itself. Despite this enormous load the aeroplane rose without any perceptible difficulty. The machine was a biplane of special design, built by Breguet himself.

Following this, Sommer carried seven people for 1 hour 31 minutes, Moineau took two people for a two-hour cross-country trip, while the two-man altitude record was put at 9,840 feet by Prevost, and the three-man distance record was jumped to 69 miles. Hirth took a passenger from Munich to Berlin, 330 miles, and Renaux carried a passenger with him the entire distance of the European circuit, a race of 1,073 miles. These are only the most prominent passenger-carrying flights, it being conservatively estimated that the French machines turned out during 1911 alone carried a total of 5,000 passengers during that year while probably a lesser number were carried in all the other countries put together.

At the Chicago Meet in August, 1911, Sopwith carried two people besides himself in a Wright biplane at 34.96 miles per hour, while at the same meet Parmalee carried 458 pounds weight. At the Nassau Meet, in September of the same year, Lieutenant Milling carried two passengers for nearly 2 hours.

Speed. Speed records kept pace during 1910 with those for duration, passenger carrying, and altitude, speeds in excess of 70 miles an hour having been attained, and it was then thought that any increase over this could be achieved only by radical departures in design. With the exception of the record for 2½ kilometers (1.5 miles), all records for that year of from 5 to 90 kilometers (3 to 55.8 miles) were made by Le Blanc in a Bleriot at one time—the Gordon-Bennett trophy race at Belmont Park. During 1911, his figures were left way behind in every one of the great European races. Vedrines made 93 miles an hour in a Morane monoplane, while during the Paris-Madrid race he flew at the rate of 135 miles an hour with a following gale. Weyman made an average of 78 miles an hour over a closed circuit in a Nieuport monoplane, winning the Gordon-Bennett trophy for America.

THE FLYING MACHINE OF THE FUTURE

Now that flying has become an accomplished fact, speculation as to just what the flying machine of the future will be like is quite as rife as it ever was when mankind generally regarded human flight as one of those long-cherished illusions, which, like perpetual motion, would endure to torment the inventive mind as long as the race existed. Wondrously impossible contrivances as large as the modern sky-scraping hotel are talked of and pictured, and the imagination is drawn upon to supply details that will probably never exist elsewhere. But the developments of the past few years have been so marvelous and so rapid that some even of what now appear to be wholly fanciful machines may actually be built in the future.

With all that has been accomplished in the past five years, it is evident that the first steps have scarcely been taken. The only thing that actually has been achieved is the establishment of the principles upon which human flight is based—those elusive laws of science that had been sought in vain for centuries previous. So far as the machines themselves are concerned, they can scarcely be said to have advanced very much. They still represent the same crude assemblage of wood, wire, and canvas that the Wright Brothers and their numerous predecessors were forced to adopt for their experiments, as they represented the only materials available. Before going into this phase of the matter at any length, however, it will be of interest to take up the question as to just what type of machine is likely to survive.

Unpromising Types. *Ornithopter.* It was only logical that first attempts at flight should be patterned after nature—many were of the opinion that if man were ever to fly he must imitate the birds. Strangely enough, some people are still of this opinion, but since flight based upon a scientific study of the laws governing sustentation in the air has become a reality, they are in the minority. Man's weight in proportion to the power he is able to exert is so puny in comparison with that of the birds, as to make any possibility of development along this line out of the question. Flying with power-driven wings is likewise extremely problematical, as will be apparent when the weight that must be sustained in the air is taken into consideration. The mechanism necessary to cause huge wings to beat in imitation of the bird would not only be weighty and complicated but likewise extremely inefficient, as compared with the propeller-driven soaring plane, which in itself has a great deal of room for improvement. Yet the hope of eventually being able to fly with an "ornithopter," as this type of machine is termed, is not yet dead. A Californian, H. La V. Twining, has carried out an unusually promising series of experiments on a small scale, employing man power exerted through the medium of bicycle pedals and gearing. It is very much to be feared, however, that like the hot-air engine and numerous other inventions that appeared to promise great results from the success achieved with a small model, the ornithopter would be about as cumbersome and hopeless as its name, when attempted on a scale large enough to be of any practical use.

Helicopter. Just as there is a certain class that still looks to the ultimate development of the ornithopter, so is there likewise another class which does not appear to be influenced to any great extent by the fact that flight is an *established* fact. This latter class pins its faith to the *helicopter*—which affords a still further example of how misleading may be the results obtained with a small model, as related by the Wright Brothers in their experience with toy helicopters. A helicopter consists essentially of a motor and a propeller, the propeller being designed to rotate in a horizontal plane and to carry the machine and the aviator aloft by reason of its downward thrust. This is the simplest type of helicopter, next to the toy of the same name, but there are other types which differ only in the elaboration of their detail, or in their combinations with other elements, such as planes, which tend to obscure their true character. Usually, two propellers have been employed, designed to turn in opposite directions, in order that the tendency of one to rotate the whole machine with it could be offset by the other. The fallacy of the helicopter seems very self-evident, and yet large sums of money and no little inventive effort have been expended in attempting to evolve something practical out of the principle of sustentation by means of the thrust of a horizontal propeller. If the object of a flying machine were merely to shoot straight up into the air from the ground like a rocket, it might be worth something to be able to start into the air without the necessity of running along the ground, which is the chief advantage claimed by its advocates, though but one helicopter has

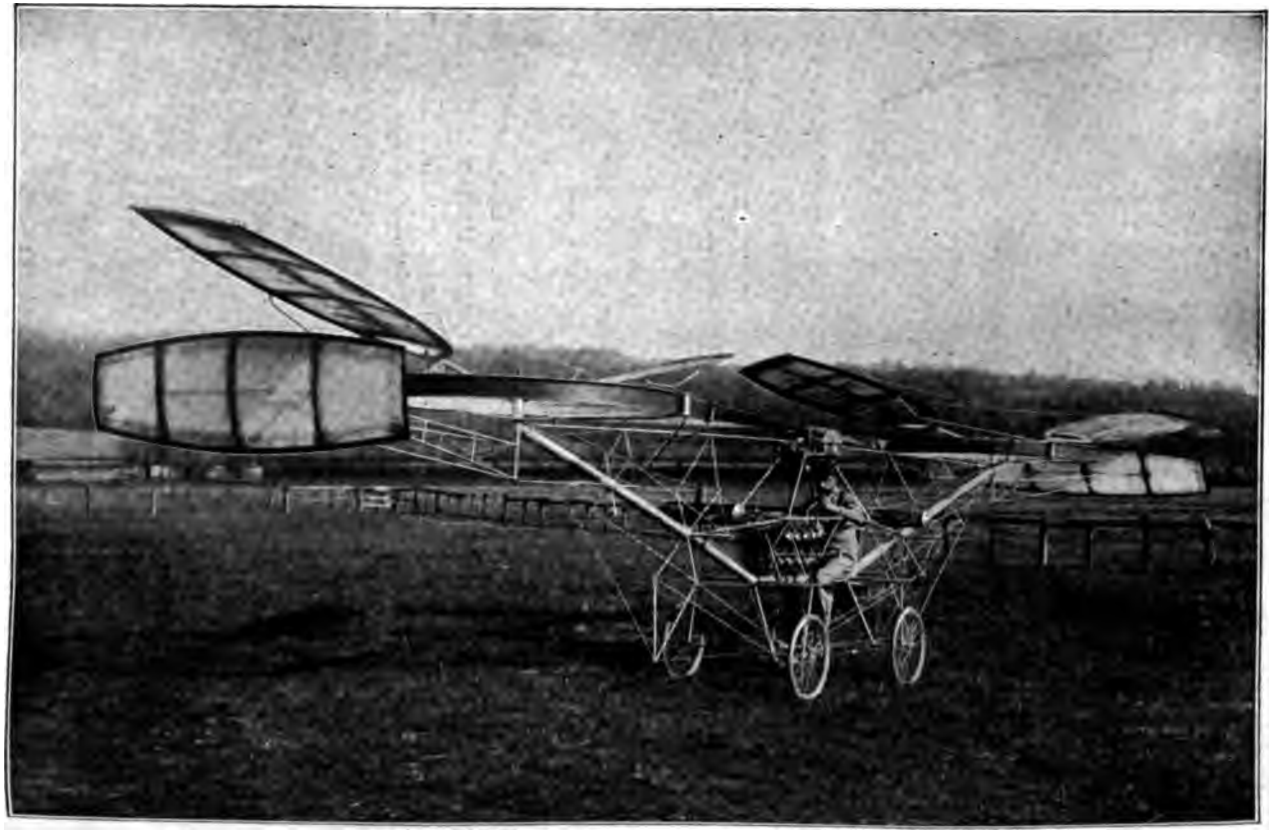

Fig. 16. Cornu Helicopter, Probably the Only Machine of This Type Which Has Been off the Ground

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ever done so with an aviator. But the single reason for the existence of the aeroplane is the same as that of the locomotive, the steamship, the automobile, the bicycle, and the wagon—transportation—and the ability to ascend straight up into the air does not bring with it any capacity for traveling in a horizontal plane.

In addition to being unable to move except in a vertical plane, the helicopter likewise has the somewhat serious disadvantage of being totally without any supporting surface in case of failure of the motive power, and even with the highly developed internal combustion motor of the present day, it would indeed be a foolhardy aviator who would risk his life in a machine in which the failure of the power for even a moment meant certain death. Paul Cornu, a Frenchman, developed this type far beyond any of his contemporaries, Fig. 15, and he is said to have actually succeeded in getting off the ground, thus showing an advance in that highly important particular over other helicopter machines so far built. This machine is likewise an improvement in design, as the propellers are so mounted that they

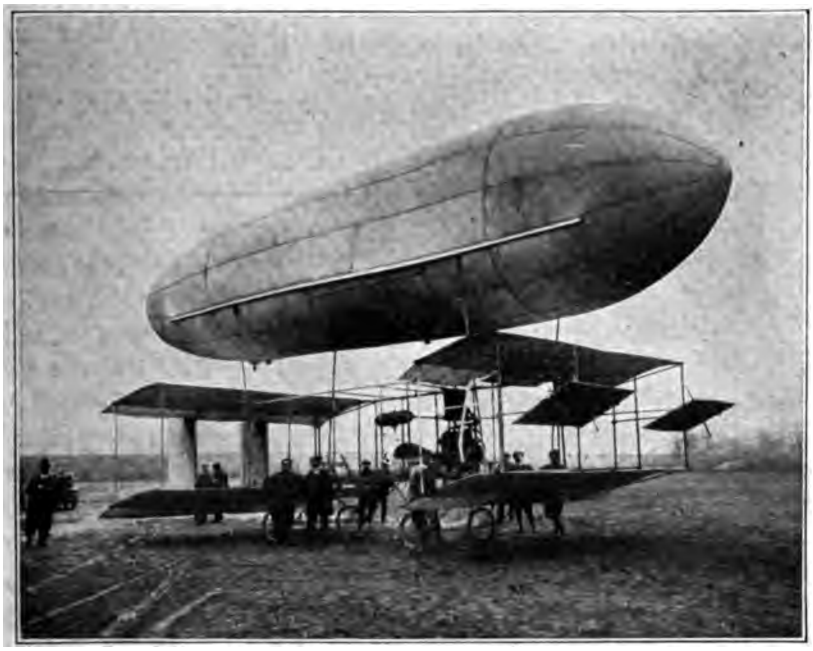

Fig. 16. Combination Dirigible and Aeroplane

can be turned at an angle, as was the case with Wellman's dirigible, the idea being that once in the air at the desired height, the thrust of the propellers, or at least one of them, could be exerted in a horizontal direction, while the other served as a support, thus providing for horizontal travel. Coming down from a height of 9,000 feet with a dead motor, as has been done in an aeroplane, would be a brief and exciting experience in a Cornu helicopter. Another attempt to provide a means of horizontal travel took the form of inclined planes. These were not intended in any way for support, but merely to send the machine ahead by reason of the reaction of the thrust of the horizontal propellers upon them. At the present writing, it seems highly improbable that anything practical will ever be done with either the ornithopter or the helicopter.

Fig. 17. Freak Type of Biplane Which Has Actualy Flown

Miscellaneous. Apart from the types mentioned, there are hundreds that could not be classified except as freaks, the majority of which are not worth even passing mention. One of these, the chief merit of which appears to be its novelty, is illustrated in Fig. 16. This is a combination dirigible balloon and aeroplane, though just what is to be gained in evolving such a hybrid is difficult to explain. It is neither one nor the other and has the disadvantages of both without the merits of either. The gas bag is not of sufficient size to effectually support any weight while, on the other hand, it is so large as to prove practically an anchor for the aeroplane, which could make but a very slow speed with such an encumbrance.

Another freak type, one of the few such machines that had really flown, is shown in Fig. 17.

Monoplane vs. Biplane. Whether the ultimate flying machine will be of a type radically different from those with which we are now familiar, or purely a development of the present types, is a question that can scarcely be answered satisfactorily. Any attempt to do so would be merely a delving into the realms of speculation, and those most thoroughly versed in the art as developed up to the present day are most reluctant to venture an opinion. As in other fields, it is usually the man who knows least about the subject who is anxious to prophesy a revolution in design. But leaving out of consideration altogether the question of the development of some entirely new type—at least new as compared with the machines at present in use, such as the ornithopter and the helicopter—there is a great deal of difference of opinion between aviators and builders as to whether the *monoplane* or the *biplane* will eventually reign supreme.

The advocates of both are equally enthusiastic and equally positive that the particular machine they favor is the only practical type. Even in their present stage of development both have exhibited marked characteristics and peculiarities of their own. The biplane has great stability and ease of maneuvering in the hands of a skilled pilot, while the monoplane has carried away all records for speed. With the materials at present employed, the biplane is an easier machine to construct and can likewise be made safer so far as its structure is concerned. It is also an excellent weight carrier, though the development of the Bleriot "bus" which has a capacity of eight passengers, shows that the monoplane is not at all lacking in this respect. Neither the disadvantages nor the advantages all lie with either type—both have numerous merits, and where the question of speed is paramount, the superiority of the monoplane must be conceded. When a comparison of the good and bad points of the two is made, it seems evident that both will always have numerous advocates and staunch supporters, and that unless something radically new in the design of one makes it immeasurably superior to the other, both will continue to develop contemporaneously.

Improvements in Construction. From an engineering point of view there can be no question but that the greatest room for improvement at present exists in the construction. When inventors were struggling with the problem of flight, and even for the first few years after the principles which made it possible, were definitely established, there was every reason why the cheapest and easiest materials to obtain should be employed; likewise for their assembly in the simplest and most expedient manner. Financial limitations, if no other, made this imperative. But now that that day has passed and aeroplane building companies, or at least those marketing the well-known standard types, are possessed of ample capital and facilities, while special materials are at hand for the purpose, there appears to be no reason why the present-day crude assemblage of *canvas, wire,* and *sticks,* which compose the average biplane or monoplane, should continue to survive longer. Lightness is absolutely essential, but it can be obtained with materials which have greater strength and durability and which may be assembled with greater security than is the case at present, viz, steel and aluminum, the latter term naturally including the numerous aluminum alloys marketed under different names. Hardness and tensile strength have been developed to such a degree with aluminum and magnesium alloys, still preserving their extreme lightness, that there is no longer any reason for the continued use of either wood or canvas. These alloys are naturally far more expensive, while the use of any metal not only involves greater manufacturing cost but also more difficulty in construction at the outset. Nevertheless, it is safe to say that the machine of the future will be built entirely of metal.

A step in this direction is to be seen in Paulhan's new all-steel machine, illustrated in Figs. 18 and 19. In this, both wood and cloth have been dispensed with entirely. The planes, as well as the struts, braces, and the like are all of steel, and the greater security of fastening which this affords makes it possible to eliminate many of the otherwise indispensable guys, which, while of small cross-section in themselves, create considerable resistance. That the use of steel in this connection means weight saving is evident from the fact that this machine tips the scales at only 770 pounds, although it has a spread of 33.5 feet. Its efficiency is obvious from its comparatively small supporting surface of 470 square feet. The power plant consists of a 50-horse-power revolving Gnome motor, so that the machine carries 9.4 pounds per square foot of area, which is an unusually good showing. The aviator's seat and protecting car containing all the controls is placed between the main planes, which marks a radical departure from the customary plan of placing them on the lower plane frame.

Fig. 18. Paulhan's All-Steel Biplane

This construction would hardly be permissible upon the usual wood-frame biplane, as the struts to support the aviator's weight would

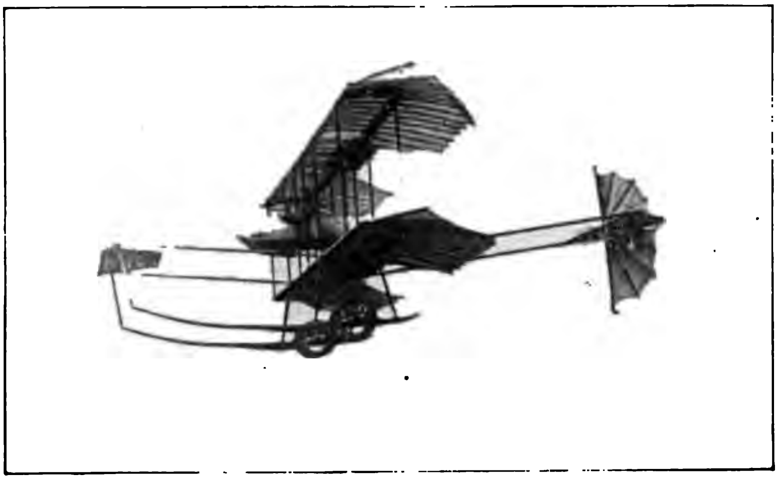

Fig. 19. Paulhan's All-Steel Biplane in Flight

have to be very much heavier than usual, while the necessary bracing to hold the seat rigid would also involve weight to an almost prohibitive extent.

That aviators generally have had in mind the employment of metal for construction is evident from numerous instances. John D. Moissant, who was the first to fly from Paris to London and whose skill and daring gained him many admirers, completed several months before his death at New Orleans, in December, 1910, the design of a monoplane to be built entirely of aluminum. Such a machine was constructed and undoubtedly would have been successfully developed, had its inventor lived. Quite a number of others have since built machines either partly or entirely of metal and the strong tendency toward its use was very marked in the machines exhibited at the Paris Salon, December, 1911. Damage to a metal framed and winged aeroplane is naturally much more difficult and expensive to repair so that the use of steel and aluminum can hardly become general until the experimental stage is left behind. The necessity for warping the wings in accordance with the principles laid down by the Wright Brothers, a device which is now almost universally employed, presents no particular difficulties of construction in connection with the use of a metal supporting surface.

Racing Machine of the Future. As the result of a study of recent developments, J. Bernard Walker has outlined in the *Scientific American*, the plan of the racing machine of the future, as follows:

> The future high-speed flyer will possess the same tapering, rounded body and the narrow, wide-spread wings which characterize the swiftest of birds—the albatross. Langley showed that the leading portion of the plane is most efficient because it is constantly moving on to fresh, undisturbed bodies of air. As the after portion of the plane has to work upon air which has already received a downward velocity, this air is unable to exert the effective reaction provided by air that is inert. Hence, a plane 5 feet wide by 10 feet long becomes more efficient when divided longitudinally, making it 2½ feet wide by 20 feet long. The wings will accordingly be long and narrow, and when made of metal, it will be possible to give them the sweeping, rounded forms, which prevent eddy making. .The body will be of a generally circular or oval section and, to allow of a long and gradual taper for ease in traversing the air, will have considerable length, this adding greatly to the fore-and-aft stability in flight.*
>
> The present wood, canvas, and wire construction will have to go. It is a makeshift at the best and was adopted because, in the early days of experiment, it offered a cheap and light combination of material, and one which, in the event of the inevitable breakages, could be cheaply and quickly repaired. Its place will be taken by some of the many remarkable alloys of steel now

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*Several bodies of this type were shown on some of the French machines at the Paris Salon, December 1911.—Ed.

available—metals of enormous strength and toughness in proportion to their weight. The use of these coupled with careful designing by the skilled engineer, will make it possible to produce an aeroplane of much greater strength that will weigh no more than the present machine, and will present far less resistance.

The principal resistances encountered by an aeroplane are those due to the lift and the head surface. That due to the lift is fairly constant, for as the speed increases, the angle of incidence decreases, and there is always an adjustment between the two which provides sufficient vertical reaction at all times to lift the weight of 500 to 1,000 pounds, as the case may be. The head resistance, however, increases approximately as the square of the speed, and if it be 100 pounds, say at 40 miles an hour, it will rise to 400 pounds at 80 miles an hour. Hence, in a racing machine, the great importance of reducing the head surface to the least possible limit consistent with structural requirements. It is this consideration of head resistance which has doomed the biplane as a purely racing type. When Octave Chanute built the first biplane glider, with its light but very rigid Pratt trussing of vertical wood struts and diagonal wire tires, he produced an excellent piece of engineering construction, which has proved to be ideally adapted to the early experimental stage which is now drawing to its close. But for high-speed results, because of the large amount of head surface presented, the Pratt truss was doomed to ultimate extinction. Unquestionably, the higher speed attained by the monoplane is due largely to the fact that its trussing is simpler, and the head surface, particularly of the wire stays, is relatively much less. The great amount of resistance offered by the apparently negligible surface of the thin wires was shown by Langley's experiments to be due to the fact that the rate of vibration of the wire under the rush of air is so great that it practically presents a solid surface, the width of which is equal to the amplitude of vibration. Hence, a tightly-strung wire offers an amount of resistance which is seemingly out of all proportion to its actual surface.

It follows, then, that even the simple king-pin trussing of the Bleriot and Antoinette types must go if we are to achieve the highest speed which is predicted for the future racing machine. This will be possible only if some high-grade sheet metal is substituted for the canvas of the wing surface, and the necessary transverse bending strength is secured by means of plate-steel members enclosed within the wing surfaces and strongly riveted to the structure of the main body of the machine. Turning to nature for guidance again, we find that the fast-flying birds fold their legs snugly beneath them when in flight. The racing aeroplane must do the same.

Mr. Walker goes on at some length detailing the construction of such a machine, as well as of a special folding chassis, operated by compressed-air cylinders, which would act to cushion the shock of landing. He also purposes to operate the movable wing tips by similar power, a two-way valve to the cylinders being controlled by a gyroscope, which may be rendered inoperative when it is desired to make a turn. After it has been sufficiently developed by experimental work, he thinks it conservative to expect a speed of 100 to

125 miles. As nearly 80 miles per hour has already been attained with the present construction, this estimate does not appear to be overdrawn.*

Reefed Supporting Surfaces. Another feature that is likely to become a subject of attention shortly and which will undoubtedly have considerable influence on the development of the machine of the future, is that of a variable supporting area; in other words, a method of "reefing" the supporting surface to adapt its area to the speed of the machine. Aeroplane speeds have already reached a point where this is to the fore. The demand for a variable surface is based upon one of the most important of the laws of flight, viz, that the area of the necessary supporting surface of an aeroplane varies inversely as the square of the velocity. This principle, affirmed by Langley and embodied in his great work "Experiments in Aerodynamics," has been disputed by some European theorists and practical aeroplane builders, but the experience of the past two years appears to verify it. If the law holds good, the standard Wright biplane of 1910, which, with about 500 square feet of surface, has a speed of 40 miles an hour, at 60 miles would need only 222 square feet for support, and at 100 miles, only 80 square feet.

That the principle is generally correct, or, at least, that its application does not produce too great a reduction of surface, is shown by the racing machines exhibited and flown by the Wright Brothers at the International Meet in the autumn of 1910. One of these, a semi-racer with a speed of 60 miles an hour, was provided with only 150 square feet of supporting surface. The standard Wright machine, driven at 60 miles an hour, would need, according to this law, 222 square feet. Its weight, however, with the aviator and full fuel and water supply, is 1,075 pounds, whereas the semi-racer weighs with pilot and fuel only 760 pounds. The difference in weight would account largely for the reduction of the area from 222 to 150 square feet of sustaining surface. Further verification is found in the Bleriot racer, which, with slightly less speed, and a weight of about 650 pounds, including the aviator, also has less than 150 square feet of sustaining surface. It is significant that in their actual racing machine, which is 15 miles an hour faster, the Wrights did not

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*The internally braced wing came into existence in the Antoinette armored monoplane (see Special Types) in 1911, and the 100-mile an hour mark was reached in February, 1912 (see Aviation Records).

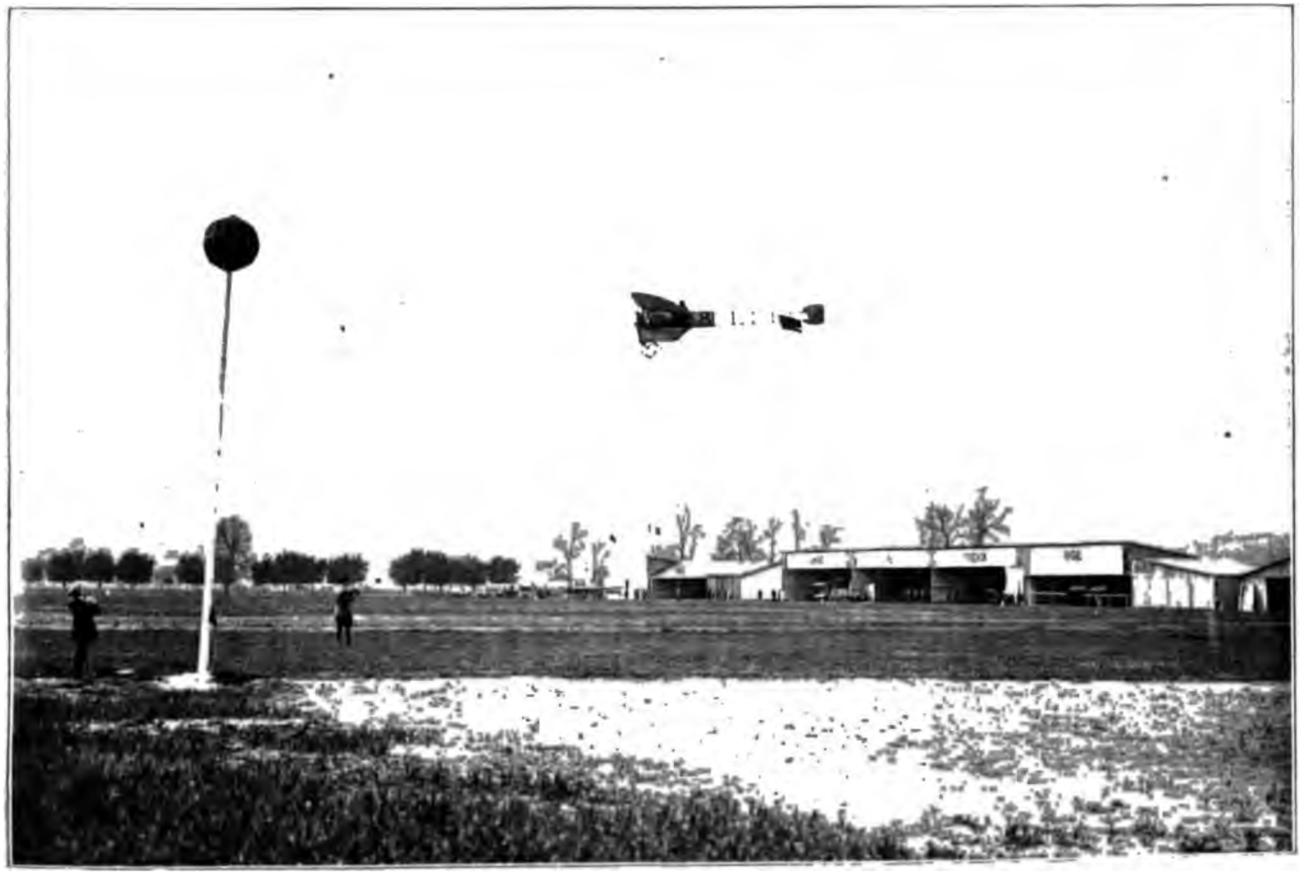
attempt to reduce the supporting surface any further, both the semiracer and the racer having 150 square feet of surface. The racer, however, is heavier, weighing about 900 pounds ready to fly.

If, then, the high-speed flyers endorse Langley's law, it follows that there will be a further reduction of area in the racing machines of the future. If the standard Wright machine with 500 square feet of surface could be driven at 100 miles an hour, it would need only 80 square feet of surface for support, and if a speed greater than 100 miles per hour were accomplished, the sustaining surface would come down to a pair of long, narrow blades, approximating in form the wings of the swift or the swallow. But it must be remembered that these reduced surfaces are equal to their work only if the machine is being driven at its highest or, at least, at a high velocity; and they are, therefore, theoretically too small to lift the machine from the ground or allow it to return safely at the lowest speeds which are necessary in starting and alighting. Proof of this was shown in the accident which disabled the Wright racing machine in the contest for the international trophy at Belmont Park, when the stopping of the motor and the sudden slowing down of the biplane caused it to drop so swiftly to the ground that its momentum partially wrecked the machine and threw the aviator from his seat. Probably, having been accustomed to the larger surface Wright machine, he did not realize the necessity of descending with the main planes at a large angle of incidence in order to check the velocity. In any case it is evident that if the racing aeroplane reaches a speed of 100 miles an hour, it will be necessary for safe control to provide it with some means of enlarging or reducing the supporting area proportionately to the speed, or of altering the angle of incidence of the wings to generate increased resistance for alighting safely.

This problem should not be particularly difficult of solution. The additional surface could be arranged to be drawn under or within the main surfaces either from the ends or from the rear. If, as seems quite likely, the aeroplanes of the future be built entirely of metal, the problem will be much easier to work out. A large percentage of the accidents to existing machines are due to descending and landing at too great an angle or at too great a speed. Were it possible voluntarily to increase the surface at the time of making a landing, the risk of accident from this cause would be greatly reduced.

Duplicate Power Plant. Another trend of development that is receiving considerable attention is the design of an aeroplane provided with two motors, either one of which may be employed to drive the propeller or propellers, in order to avoid the necessity of alighting should the motor stop, as is the case with present machines. Such a contingency involves no great danger when flying over an aviation field, but in cross-country flights the matter of finding a suitable place to alight in an emergency is something that the aviator prefers not to have to decide. Edwin Gould has offered a prize of $15,000 for a successful machine of this type, which will be competed for through the *Scientific American.*

In the foregoing, no attempt has been made to point out all the possibilities of the future machine. So much has been accomplished in such a marvelously short period and so much will undoubtedly be brought about in the next few years, that it would be idle to do more than bring to notice a few of the salient features which most likely will receive the greatest share of attention in the near future.



[illegible] HOUR

GLOSSARY

A

Acceleration. The rate of change of velocity of a moving body.

Adjusting Plane. A smaller plane of an aeroplane, generally placed at the end of the wing tip and adjusted to maintain lateral balance. A *stabilizer* placed at the end of a wing tip.

Adjusting Surface. See *Adjusting Plane.*

Advancing Edge. The front edge of any of the surfaces of a heavier-than-air flying machine. Synonymous with *Attacking Edge.*

Advancing Surface. A surface of an aeroplane that is ahead of another surface.

Aerial. See *Antennae.*

Aerodrome. A ground set apart for flying purposes. (Langley's term for his flying machines.)

Aerodynamics. The science of atmospheric laws, *i.e.*, the effects produced by air in motion.

Aerofoil. A substitute proposed for *Aeroplane.*

Aeronat (air swimmer). A term sometimes applied to dirigible balloons.

Aeronaut. An aerial navigator.

Aeronautics. The entire science of aerial navigation.

Aeronef. Proposed term for flying machine. (Not likely to come into general use.)

Aeroplane. A power-driven heavier-than-air machine.

Aerostat. A lighter-than-air flying machine depending upon the use of a volume of gas whose specific gravity is less than that of the air, but having no means of lateral guiding; an ordinary balloon.

Aerostatics. The science of buoyancy in the air by displacement.

Aerostation. That part of the science of aeronautics that deals with "lighter-than-air" or gas-lifted machines.

Aileron (French). A small wing or plane, either attached to the rear edge of the main planes as in the Farman, or between them as in the Curtiss biplane.

Air Bag. One of several small bags within a balloon. These bags are connected with an air pump, and by increasing or decreasing the amount of air in the bags the pressure of gas within the balloon may be regulated. Also called *Balloonet.*

Air-Resistance. The resistance encountered by a surface in motion. This resistance increases as the square of the speed, which makes it necessary to employ four times as much power in order to double a given speed. A monoplane has usually less resistance than a biplane, which accounts for the greater speed of the former. While it is desirable to reduce this retarding force to a minimum, a certain amount of resistance is required to produce sustentation in the air.

Airship. A dirigible balloon.

Alighting Gear. The mechanism on the under part of an aeroplane to cushion its descent and bring it to a stop upon reaching the ground. It usually consists of pneumatic-tired wheels with a spring frame, or of skids, the starting gear and alighting gear nearly always being combined. Also called *Running Gear.*

Anemometer. An instrument for measuring the force or velocity of the wind, or both. Anemometers are made of several types: (1) Suction and pressure anemometers, which indicate in a more or less direct manner by the deflection of a spring or of a suspended plate of accurately determined weight, or by causing water to rise in a tube. (2) Rotating anemometers which, by the continual revolution of a horizontal spider carrying vanes or cups at the ends of its arms, directly indicates a measure of its movement from which its velocity may be computed. Some anemometers indicate the distance traveled by the wind in a specified time, from which its velocity can be calculated.

Angle of Attack. Practically synonymous with *Angle of Incidence.*

Angle of Incidence. The angle that a plane makes with an imaginary horizontal line when flying.

Antennae. Wire or wires for intercepting electromagnetic radiations in the air and leading them to "wireless" receiving instruments.

Arch. A downward curve given the ends of a winged surface.

Area, Effective. This usually covers the entire area of the flying machine, including elevating planes as well as the main planes, and is that of the plan form, so that it is measured in units of double surface, *i.e.*, both sides or surfaces are counted as one unit of area. Thus, by an area of 500 square feet is indicated a surface of twice 500 square feet.

Area, Supporting. See *Area, Effective.*

Aspect Ratio. The proportion that the length or "spread" of the supporting surfaces bear to their depth.

Aspiration. The action of a current of air flowing against the edge of a spiral curved wing or aeroplane surface, by which the surface is drawn toward the current; also called *tangential force.*

Automatic Stability. The maintaining of lateral and longitudinal stability of a flying machine independently of the control of the operator.

Aviation. The science of dynamic flight by means of heavier-than-air machines.

Aviator. The operator of a heavier-than-air flying machine. Strictly, the form of flying machine.

B

Balance, Dynamic. Equilibrium of the machine in flight. See *Stability.*

Balance, Static. Standing balance; equilibrium of the machine when stationary on the ground.

Balancing Plane. A surface whose position or angle may be changed to steer or maintain balance.

Balancing Surface. Same as *Balancing Plane.*

Banking. The tilting of an aeroplane to increase its resistance and prevent skidding or "sliding off" in rounding a turn.

Barograph. An automatic recording barometer employed to record the height to which an aeroplane or dirigible ascends.

Biplane. An aeroplane with two superposed main planes overlapping in plan form.

C

C. Abbreviation for a centigrade degree of temperature.

C. G. S. System. Abbreviation for centimeter-gram-second system of measurement; the standard system in scientific work.

Camber. The greatest depth of curvature of a surface or plane.

Canard (French "Duck"). A type of monoplane or biplane that has all auxiliary surfaces in front and apparently flies backward. So called owing to its resemblance to a duck in flight.

Cavitation. Effect of revolving a propeller at an excessive speed for its pitch and diameter, creating a "hole," so to speak. The fluid, water or air, is carried round by the blades of the propeller in the same plane, instead of being thrust back.

Center of Effort. See *Center of Thrust.*

Center of Gravity. The point of a body about which all portions are balanced.

Center of Lift. A mean of all the centers of pressure.

Center of Pressure. A line along the under side of an aeroplane surface, on either side of which pressures are equal.

Center of Thrust. A point or line along which the thrust of the propellers is balanced.

Centigrade Scale. The thermometer scale invented by Celsius. Used universally in scientific work.

Centripetal Force. A force tending to draw things toward a center (as opposed to centrifugal force).

Chord. An imaginary straight line connecting the ends of the arch or camber of a plane.

Cloche (bell). Bell-shaped device employed in the Bleriot control.

Control, Longitudinal. This consists of the elevating rudder and its operating connections.

Control, Throttle. Method of governing the power of the engine by altering the area of the passage leading to the admission valve so that the amount of the fuel introduced into the cylinder is varied.

Control, Transverse. Levers and connections for warping the wings or moving ailerons to maintain transverse stability.

Critical Speed. Rate of travel at which an aeroplane propels and sustains itself most efficiently.

D

Dead Surfaces. Those which exert no lifting power, such as fins, keels, nonlifting tails, etc.

Depth. Dimension of a plane parallel to its direction of flight.

Dihedral Angle. Upward inclination of the planes at an angle to each other in the form of a **V**.

Direction Rudder. The vertical rudder by means of which an aeroplane or dirigible is guided in exactly the same manner as a ship.

Dirigible. Steerable; drivable; usually applied to lighter-than-air flying machines which may be propelled and guided.

Disk. The circle of air upon which a propeller acts.

Drift. The resistance of an aeroplane surface to forward movement.

Drome. Word suggested for the flight of aeroplanes.

E

Elevating Rudder. A horizontal rudder or plane, the angle of incidence of which may be altered to cause an aeroplane or dirigible to ascend or descend.

Elevator. A horizontal rudder for steering upwards or downwards.

Empennage (French). Feathering of an arrow—as applied to the rear stabilizing planes of a dirigible.

Epinage (French). Tail—all of that part of an aeroplane back of the main supporting surfaces, particularly as applied to a monoplane.

Equilibrator. A device designed to automatically increase or decrease the amount of ballast of a dirigible flying over water. *Obsolete.*

F

Fin. (1) A vertical surface or plane designed to aid the lateral stability of the aeroplane. Synonymous with *keel.* (2) Projections cast on the cylinder of a gas engine to assist in cooling.

Flexible Propeller. A propeller whose fabric is rather loosely mounted on a framework so that it can change its form with the varying air pressures, or one in which stiff blades are pivoted and controlled manually or by springs to enable the aviator to alter the pitch in accordance with the speed.

Flying Angle. The angle of incidence of aeroplane surfaces in flight.

Flying Machine. An apparatus designed to enable persons to move about at will through the air. Strictly, the term should be applied to only that class of machines in which human flight is obtained by means of flapping wings.

Following Edge. The rear edge of an aeroplane surface.

Following Surface. A main surface that is preceded by another.

Fore-and-Aft Stability. See *Longitudinal Stability.*

Fuselage (French). The framework of an aeroplane as distinguished from the planes themselves.

G

Gas. Matter in a fluid form which is elastic and has a tendency to expand indefinitely with reduction in pressure.

Gas Bag. A gas-tight bag designed to contain gas, usually applied to the envelope of a balloon.

Gauchissement (French). Warping, also banking.

Glider. An aeroplane, without motor or propeller, for use in gliding.

Gliding. The combination of forward and downward movement of an aeroplane without power.

Gliding Angle. The smallest angle at which an aeroplane is able to glide.

Gong. A loud, clear-sounding bell usually operated either electrically or by foot power.

Gyroplane. A heavier-than-air flying machine lifted by rotating aeroplanes; a helicopter.

Gyroscope. A heavy wheel revolving at high speed, the gyroscopic effect of which is employed to give automatic stability.

Gyroscopic Effect. That property of a rotating body by virtue of which it tends to maintain its plane of rotation against all disturbing forces.

H

Hangar (French). Building used for harboring aeroplanes. Synonymous with "shed," "loft," etc.

Head Resistance. The resistance of a surface to movement through the air.

Head Surface. The edges of the planes, struts, etc., presented to the wind and causing resistance to flight.

Heavier-Than-Air. A term applied to dynamic flying machines which weigh more than the air they displace.

Helicopter. From *helix*, a screw. A dynamic, heavier-than-air flying machine, designed to be sustained by the effect of screws or propellers mounted on vertical axes and rotating in a horizontal plane.

High-Tension Current. A current of high voltage, as the current induced in the secondary circuit of a spark coil.

Horizontal Component. Amount of force acting to drive the aeroplane ahead.

Horizontal Rudder. A rudder placed horizontally for steering in a vertical plane.

Hovering. That method of flight in which a practically fixed position in the air is held.

Hydroaeroplane. An aeroplane fitted with floats or boats and designed to arise from and alight on the water.

Hydroplane or Hydroplane Float. One having its under surface so curved that it rises and skims the surface of the water when traveling at high speed

I

Incident Angle. See *Angle of Incidence.*

Inherent Stability. Stability of an aeroplane due to its design and arrangement of supporting surfaces, as distinguished from automatic stability due to an extraneous device or attachment.

K

"K." Symbol denoting a constant, or coefficient, used in calculating air resistance.

Keel. The underframing placed longitudinally under flying machines to stiffen the structure. More usually employed in dirigible balloons.

L

Landing Area. A specially prepared surface for the alighting of flying machines.

Lateral Stability. Stability in a lateral direction, or from side to side.

Leeway. Movement at right angles to the course being steered, caused by the lateral drift of the atmosphere or by centrifugal force acting on the aeroplane in rounding a turn.

Lift. The sustaining effect of a wing surface or aeroplane surface.

Lighter-Than-Air. A term applied to an airship weighing less than the air displaced by it.

Locus (Latin). Point, or place, as referred to in describing movement of center of pressure.

Longitudinal Stability. Stability in the longitudinal direction.

Lubrication, Splash. Method of lubricating an engine by feeding oil to the crank case and allowing the lower edge of the connecting rod to splash into it.

Lubricator. A device containing and supplying oil or grease in regular amounts to the working parts of the machine.

M

Main Plane. The main supporting surface of an aeroplane.

Monoplane. An aeroplane having one main supporting surface.

Meteorology. The science that treats of atmospheric conditions, their changes, and effects.

N

Non-Lifting Tail. An auxiliary surface at the rear of an aeroplane which does not aid in the support of the machine.

O

Ornithopter. A heavier-than-air, or dynamic, flying machine in which flapping wings are used for lifting and propulsion.

Orthogonal. A term used to designate flapping flight.

Orthopter. Another spelling for *Ornithopter.*

P

Panel. A vertical surface. Analogous to *keel* and *fin.*

Peripheral Speed. Rate at which the tips of the propeller blades travel in rotating.

Pilot. The operator of a flying machine. Strictly, one who is licensed by an aeronautic club.

Pisciform. Fish-shaped, as applied to the envelope of a dirigible.

Pitch. The theoretical distance traveled forward or backward by a screw propeller in one complete revolution.

Pitch, Variable. An increasing or decreasing pitch, as applied to a propeller blade, in contrast with the true screw.

Pitch Coefficient. See *Pitch Ratio.*

Pitch Ratio. The proportion that the pitch of a propeller bears to its diameter.

Plane. A flat, or approximately flat, surface.

Propeller Reaction. The tendency of a single propeller to revolve the vehicle to which it is attached in the opposite direction.

Pylon (French). A pole placed on an aviation field to mark the course.

R

Reactive Stratum. The stratum of air which is compressed beneath an aeroplane surface or behind the blade of a propeller.

Resiliency. That property of a material by virtue of which it springs back or recoils on removal of pressure, as a spring.

Rib. A part of an aeroplane to give the correct shape to the wing section.

Rigid Type Dirigible. An airship in which the envelope is supported on a frame and does not depend upon its inflation to maintain its form.

Rising Angle. The angle at which an aeroplane ascends.

Rudder. A surface for steering.

Runner. A part of alighting gear used in place of wheels, and resembling sled runners. Also called *skid*.

Running Gear. The landing *chassis*, or frame and wheel arrangement, by means of which the aeroplane runs along the ground and upon which the aeroplane lands at the end of a flight.

S

Semi-Rigid Type Dirigible. One having the car, motors, etc., supported by a rigid frame, the gas bag depending upon its inflation to maintain its form.

Single-Surfaced Plane. Having fabric on upper side of ribs only.

Skid. See *Runner*.

Skidding. Tendency of an aeroplane to make leeway or "slide off" in rounding a turn when not properly banked.

Skin Friction. The resistance set up by a moving surface, such as that of the supporting planes or propeller blades.

Slip. The reaction of a propeller on the air, by which it is enabled to create thrust.

Soaring Flight. Gliding flight in an upward direction.

Speed, Peripheral. See *Peripheral Speed.*

Stabilizer. A surface for automatically maintaining balance.

Stabilizing Fin. A vertical auxiliary surface to give lateral stability.

Starting Rail. The rail upon which an aeroplane is run to give the initial velocity necessary for starting. *Obsolete.*

Strata. Well-defined layers of moving air or wind.

Stream Lines. Easy curves from head to tail of a dirigible or aeroplane, as in the pisciform shape, which minimizes head resistance.

Striae. Literally "streaks" in the wind; *i.e.*, narrow strata moving at a different speed or different direction to the surrounding air.

Struts. Vertical supporting members between the main planes of a biplane.

Supplementary Surface. A surface which is small compared with the main surfaces of an aeroplane for steering or balancing.

Sustaining Surface. A horizontal surface for the purpose of maintaining a horizontal position; the main plane.

T

Tail. The rear part of a flying machine to improve its stability and afford attachments for rudders and stabilizers.

Tangential. The forward inclination of the lifting force under certain conditions, such that the surfaces tend to advance into the wind.

Thrust, Dynamic. The work done by the propeller in forcing the aeroplane ahead. It equals the weight of the mass of air acted upon per second times the slip velocity in feet per second.

Thrust, Static. The work done by the propeller when forcing a column of air backward, the machine being stationary.

Tractor Screw. A propeller placed forward to draw the aeroplane after it, in contrast with a propulsive screw which forces it ahead.

Trailing Edge. Rear edge of a plane in its direction of travel.

Triangulation. A method of ascertaining the height of an object by sighting from two points on a base line to obtain two angles of an imaginary triangle. Already obsolete in aeronautics.

Triplane. An aeroplane having three superposed supporting surfaces.

True-Screw Propeller. A propeller in which the pitch is uniform, as in a metal screw thread. See *Pitch, Variable.*

U

Uniform Pitch. A changing angle of blade surface from hub to tip of a propeller such that all portions of the propeller blade tend to advance through the air at the same speed.

V

Vertical Component. Amount of force exerted in a vertical direction and tending to lift the aeroplane.

Vertical Rudder. An upright rudder for horizontal guiding.

Volplane (French). To glide down from a height in an aeroplane with the motor stopped.

Vortex. A whirling column or spiral of air, usually ascending, due to temperature differences.

W

Whirling Table. A device for testing planes and propellers by revolving them through the air.

Wind Tunnel. A large tube used for experimenting with surfaces and models and so called because a current of air or wind is artificially created in it.

Wing Skid. A small skid under the tip of the wing to keep it from contact with the ground.

Wing Wheel. A small wheel under the end of the wing to keep it from contact with the ground.

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